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RUN-OFF FROM SMALL AGRICULTURAL AREAS[1]

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INTRODUCTION

The purpose of the experiments herein recorded was to determine the rates of run-off from small agricultural areas. The results are especially applicable to the design of open-ditch drainage systems, terrace systems, small diversion ditches, storm-water sewers draining areas consisting partly of farm lands, tile drains with surface inlets, and road culverts where characteristics of the watersheds and other conditions are similar to those herein described.

An area of 112 acres with well-defined divides and adequate drainage channels, situated about 4½ miles southeast of Jackson, Madison County, Tenn., was chosen as the site for these experiments. Nearly all of the area was included in a farm owned by M. N. Murchison. The experiments consisted in making rainfall and run-off measurements on six watersheds ranging in area from 1¼ acres to 112 acres.

GENERAL DESCRIPTION OF WATERSHEDS

Figure 1 shows the size and shape of the several watershed areas and the physical characteristics that affect run-off, such as timber, gullies, land slopes, and the arrangement of the main drainage channels and hillside ditches. The data for this map were obtained from a carefully made stadia and transit survey. Particular care was taken to locate accurately the divides between the watersheds so that the areas could be correctly determined. As may be judged from the contours, the topography of the tract is quite hilly; in fact, it is typical of the steepest lands under cultivation in the county. The soil is of the type known as Lexington silt loam, described by the United States Bureau of Soils [2] as follows:

> The Lexington silt loam, to a depth of about 12 inches, is a gray or yellowish-gray mellow silt loam. In the virgin state the surface 2 or 3 inches is usually slightly darker in color than the rest of the profile, owing to the accumulation of a small amount of organic matter. Where the type is under cultivation it is also usually somewhat darker in color and more friable. The subsoil to a depth of 36 inches consists either of a compact, plastic silt loam, slightly heavier than the soil, or of a silty clay varying from yellow to brown in color or sometimes tinged with red. Very often the subsoil in the lower depths is mottled yellow, brown, and gray and has a mealy texture. At an average depth of 3 feet the orange sand occurs. * * *

[1] Received for publication November 27, 1926; issued June, 1927. Prepared under the direction of S. H. McCrory, chief, Division of Agricultural Engineering.

[2] CARR, M. E., and BENNETT, F. SOIL SURVEY OF HENDERSON COUNTY, TENNESSEE. U. S. Dept. Agr., Bur. Soils, Field Oper. 1905, Rpt. 7: 643-657, illus. 1907.

The topography of the Lexington silt loam is moderately rolling to hilly. The hilly portion consists mainly of long, winding ridges, forming the watersheds between the streams, and is sparsely settled and but little cultivated. * * *

The topography gives practically all of the type excellent drainage. The character of the deep subsoil is such that considerable of the soil moisture is removed by seepage. The growing crops are seriously injured by droughts if of extended duration, but they are seldom damaged by wet weather, as are those on the lowlands. Springs are more numerous than in any other soil. * * *

About 24 per cent of the area is covered with timber. The cleared lands have been devoted to the cultivation of cotton for many years with very little protection against erosion. As a result most of the top soil on the steeper slopes has been washed away by the heavy rains and deposited over the bottom areas or carried off the watershed. The subsoil over the steeper slopes is exposed in many places and does not possess the fertility necessary to produce a profitable crop. As may be seen from Figure 1, hillside ditches have been employed to some extent to check erosion, but they have not proved to be very successful.

In Table 1 are given some data pertaining to the characteristics of each of the six watersheds. In the second column is given the size of the watershed in acres. The fall of the channels at the gauging station, the average fall from the farthest point on the watershed to the gauging station, and the maximum fall found on any of the hillsides of the watershed are given in the next three columns. This information is of use in making a comparative study with other watersheds where it is desired to apply the results of these experiments. The distance from the farthest point on the watershed to the gauging station and the time required for water to travel this distance—known as the time of concentration for the watershed—are given in the next two columns. This distance is as measured along the watercourse from the gauging station and in a direct line from the upper end of the watercourse to the farthest point on the watershed. In the last column is given the percentage of the watershed area that is covered with timber. Timber on a watershed has a decided effect upon the rates and amounts of run-off, as will be brought out later in the discussion of the results.

TABLE 1.—*Characteristics of six watersheds on the Murchison Farm near Jackson, Tenn.*

Watershed No.	Area	Fall of channel at gauging station	Average fall from farthest point to gauging station	Maximum fall	Distance from farthest point to gauging station	Time of concentration	Percentage in timber
	Acres	*Feet per 100 feet*	*Feet per 100 feet*	*Feet per 100 feet*	*Feet*	*Minimum*	
1	20.70	2.4	4.89	40	1,220	5	14.0
3	49.20	2.2	3.99	64	2,152	10	24.7
4	15.70	3.5	5.44	32	1,418	7	38.9
5	112.00	1.0	2.74	64	3,933	17	23.9
6	1.25	.....	9.78	33	359	1½	0.0
7	2.79	.....	8.53	39	672	3	55.5

METHODS AND APPARATUS

RUN-OFF

Run-off is that portion of the rainfall which finds its way through the ground or over the surface to drainage channels. In general the amount of run-off is equal to the rainfall minus the evaporation and

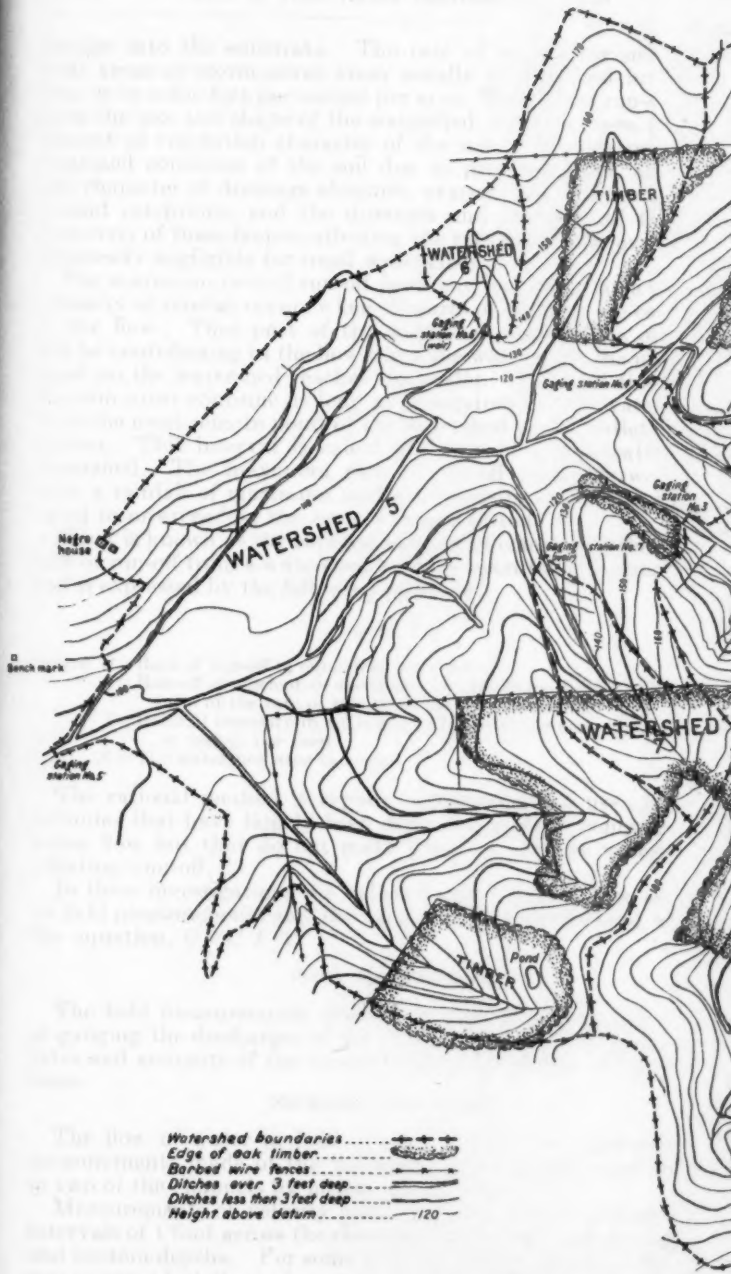

FIG. 1.—Watershed areas on the N

ens on the Murchison farm near Jackson, Tenn.

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seepage into the substrata. The rate of run-off for small agricultural areas or storm-sewer areas usually is expressed in inches per hour or in cubic feet per second per acre. The rate of run-off depends upon the size and shape of the watershed, surface slopes, nature and amount of vegetation character of the soil as regards permeability, saturated condition of the soil due to previous rains, arrangement and character of drainage channels, evaporation, storage and underground conditions, and the duration and intensity of the rainfall. However, of these factors affecting the rate of run-off, evaporation is practically negligible for small watersheds.

The maximum rate of run-off from any watershed area for a given intensity of rainfall occurs when all parts of the area are contributing to the flow. That part of the watershed nearest the outlet must still be contributing to the flow when the water from the most remote point on the watershed reaches the outlet. To fulfill this condition the rain must continue as long as is required for the water to travel from the most remote point of the watershed to the outlet or gauging station. This interval is called the time of concentration for the watershed. The maximum rate of run-off therefore would result from a rainfall of maximum uniform intensity continuing for a time equal to or exceeding the time of concentration.

What is known as the rational method of computing the maximum rate of run-off from a watershed is based upon the foregoing principle and is expressed by the following equation:

$$Q = C\ I\ A$$

Where Q = Rate of run-off in cubic feet per second.
C = Run-off coefficient or coefficient of imperviousness, representing the ratio of the rate of run-off to the rate of rainfall.
I = Rainfall intensity in cubic feet per second per acre, or approximately in inches per hour.
A = The watershed area in acres.

The rational method is rapidly supplanting the use of empirical formulas that have largely been depended upon in computing storm water flow but that do not make provision for the various factors affecting run-off.

In these investigations the values for Q, I, and A were ascertained by field measurements and the value of C was determined by solving the equation, $Q = C\ I\ A$.

FIELD MEASUREMENTS

The field measurements relating to rainfall and run-off consisted of gauging the discharges of the various channels and measuring the rates and amounts of the rainfall during the period of the investigations.

DISCHARGE MEASUREMENTS

The flow of water in four of the channels was ascertained from measurements made of the velocities and cross-sectional areas, and in two of the channels by means of weir boxes.

Measurements of velocity were made with a rod current meter at intervals of 1 foot across the channel and in most cases at top, middle, and bottom depths. For some of the gaugings, however, the velocity was measured at the surface or at 0.6 foot depth. In the three-point method the mean velocity was obtained by taking one-sixth of the

sum of the velocity at the top, four times the velocity at the middle, and the velocity at the bottom. The mean velocity for each 1-foot section was then determined by averaging the velocities in the verticals on each side of the section, and the discharge for the section was obtained by multiplying this mean velocity by the area of the section between the verticals. Discharge measurements were made for various stages in the channel, except that very few high-stage measurements were made owing to the difficulty of reaching the stations at the time of the crest flow, which usually lasted but a few minutes. The gaugings of the channels on the smaller watersheds

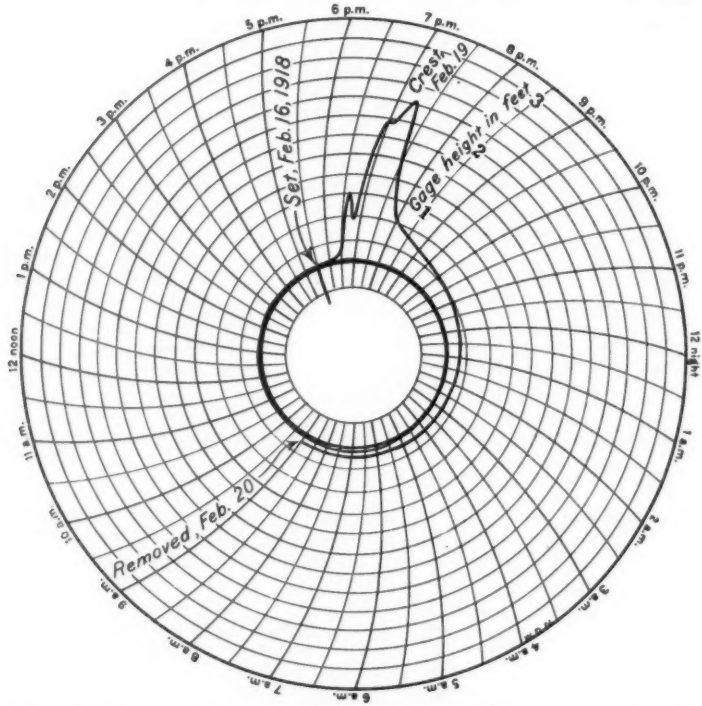

FIG. 2.—Recorder chart showing record of gauge heights for period February 16–20, 1918, at gauging station No. 5

were made during the heaviest rainfall, since the water in the channels subsided rapidly when the rain ceased. The discharge of the channels for the highest stages that occurred were computed by the Kutter and Chezy formulas, using the value n computed for the highest stage in the channel for which a gaging was made. The discharges, obtained from gauging and computations, were used to construct discharge curves for the channels, from which the discharge capacity of a channel could be determined for any stage.

Continuous records of the stages in the channels were obtained with automatic water-stage registers. Recorders were used that covered a range of 5 feet in the water level. A record of the water

stages in one of the channels obtained with the instrument used is shown in Figure 2. The amount and time of all fluctuations in the water surface are recorded on a circular chart. The chart is revolved by a clock at the rate of 1 revolution in 24 hours, and a pivoted pen which moves up and down—corresponding to changes in the water level—records the water stage continously.

The run-off from two of the smallest watershed areas was measured by means of weir boxes. These boxes were constructed in accordance with specifications prepared by V. M. Cone.[3] The weir boxes were made 20 feet long, 2 feet wide at the lower end, 2½ feet wide at the upper end, and 1½ feet deep. The bottom of each box was made level and flush with the bottom of the ditch at the upstream end. An enlargement in both depth and width of the ditch was made a short distance above the upper end of the box to serve as a catch basin to remove a part of the load of silt carried by the run-off water. This basin was found practically filled with silt and sand after every heavy rain and at the heaviest rates of precipitation considerable sand was carried through and deposited in the box. A steel weir plate was installed at the downstream end of the box, the weir being 1 foot wide and the crest flush with the bottom of the box so as to reduce to a minimum the accumulation of sand above the weir. The depth of the water in the box was measured with a recorder placed 6 feet upstream from the weir. The accumulation of silt and sand in the weir box and in the vertical flume inclosing the compensator of the recorder was the unavoidable cause of inaccuracy in some of the measurements. The following formula, derived from experimental data and contained in the article by Cone,[3] above referred to, was used in the determination of the weir discharges:

$$Q=(3.83-0.07L)\ Lh\ (1.52+0.01L).$$

Where L=length of weir crest in feet,
h=head on weir crest in feet,
Q=discharge in cubic feet per second.

RAINFALL MEASUREMENTS

Measurements of the rainfall were made with a tipping-bucket rain gauge at the location shown in Figure 1. The rain is collected in a funnel 12 inches in diameter and is poured into a bucket with two compartments each holding 0.01 inch of rain. The bucket is so supported that as a compartment is filled it tips and discharges the rain water into the receptacle below, at the same time presenting the other compartment for filling. At each tip of the bucket an electrical contact is made which causes the recording pen to make a step on the chart. The chart is carried on a cylinder that is turned by a clock at the rate of 1 revolution in six hours. The mechanism that regulates the movement of the pen is such as to cause the pen to move five steps across the chart and five steps back. Record charts from this instrument of 11 of the most intense rains that occurred during the year 1918 are shown in Figures 3 and 4. Each division of time on the chart is equivalent to 5 minutes, and it is possible to estimate the time to the nearest minute. Tests of the instrument for heavy rates of precipitation showed that owing to the

[3] CONE, V. M. A NEW IRRIGATION WEIR. Jour. Agr. Research 5 : 1127-1143, illus. 1916.

appreciable time required for the bucket to tip, a small quantity of water will flow into the bucket after it begins to tip. Tests accordingly were made to determine the amount lost in this manner for different rates of precipitation, and a correction was applied to the records of precipitation. A check on the total amount of rainfall recorded for each rain was obtained by direct measurement of the rain collected in the receptacle below the tipping bucket. The time

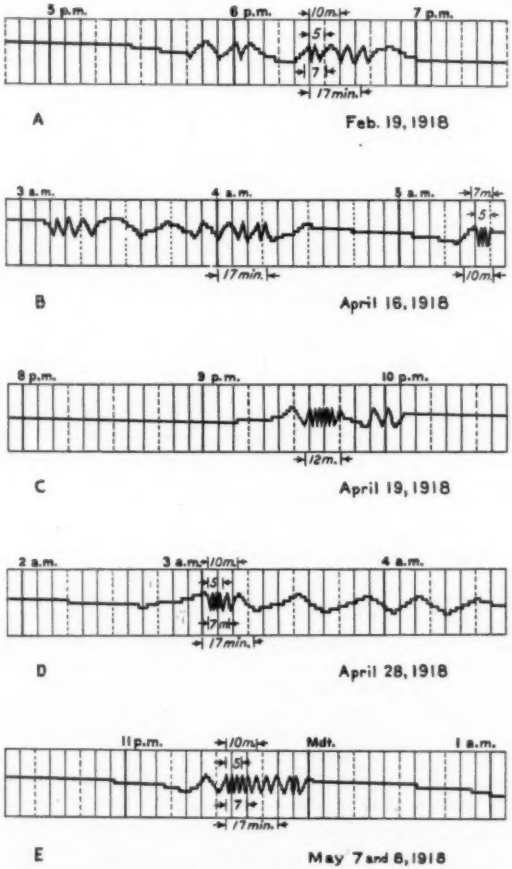

FIG. 3.—Precipitation on the Murchison farm near Jackson, Tenn., for selected storms

recorded by the instrument was checked with a watch at the time the chart was removed. An attendant living close by wound the clock and changed the charts at noon daily.

MEASUREMENTS OF RAINFALL AND RUN-OFF

The field measurements were first begun in March, 1917, and were continued throughout the year 1918. Data were secured for all rains

during this period, but since by far the most satisfactory results were obtained for the year 1918—during which time water-stage recorders particularly adapted to the needs of the experiments were used—it was not believed that the data for 1917 would add to the value of the results and conclusions. It was also decided to present the results only for the most intense rains, since the primary purpose of these experiments is to provide data on *maximum* rates of run-off.

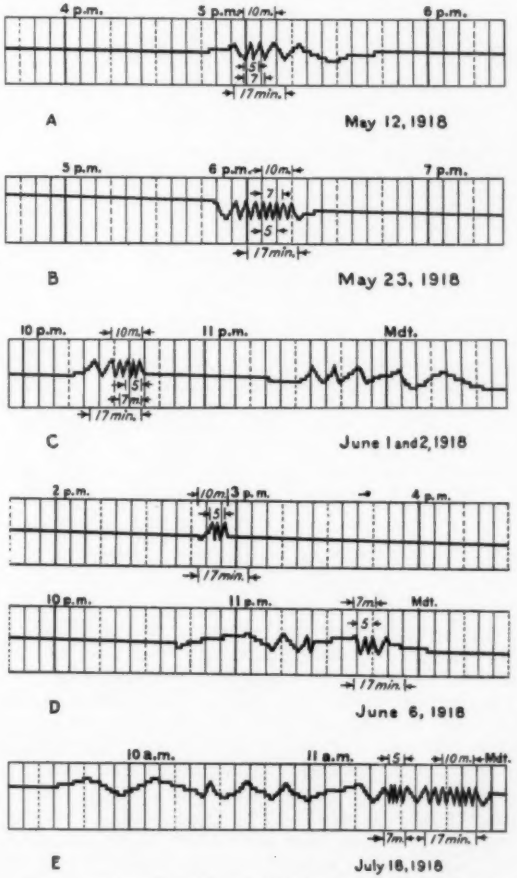

FIG. 4.—Precipitation on the Murchison farm near Jackson, Tenn., for selected storms

Measurements were contemplated on seven watershed areas, numbered from 1 to 7. (See fig. 1.) However, satisfactory data were not obtained for watershed No. 2. Owing to the "flashy" nature of the streams, which subsided as soon as the rains ended, there was not time to secure satisfactory measurements at all of the stations following each rain, and gauging station No. 2 was the last to receive attention.

TABLE 2.—*Measurements of rainfall and run-off for watershed No. 1; drainage area, 20.7 acres; time of concentration, 5 minutes*

Date of rain, 1918	Rainfall during time of concentration	Average rate of rainfall during time of concentration	Maximum rate of run-off		Coefficient of run-off (ratio of maximum rate of run-off to average rate of rainfall)	Rainfall prior to period taken as time of concentration	Previous rains over 0.08 inch		See Figure No.
							Date	Amount	
	Inch	*Inches per hour*	*Second-feet*	*Inches per hour*		*Inches*		*Inches*	
Feb. 19	0.20	2.40	20.0	0.96	0.40	0.39	Feb. 15	0.10	3, A
							Feb. 12	.41	
							Feb. 6	.20	
Apr. 16	.32	3.84	26.5	1.27	.33	1.21	Mar. 23	.23	3, B
							Mar. 20	.13	
							Apr. 20	.82	
Apr. 28	.37	4.44	38.0	1.82	.41	.09	Apr. 19	1.59	3, D
							Apr. 17	.72	
							Apr. 16	1.55	
May 7	.30	3.60	28.5	1.37	.38	.18	Apr. 28	1.01	3, E
							Apr. 20	.82	
							Apr. 19	1.59	
May 12	.16	1.92	16.5	.79	.41	.10	May 11	.11	4, A
							May 8	.45	
							May 7	1.19	
May 23	.26	3.12	32.0	1.53	.49	.38	May 20	.09	4, B
							May 18	.13	
							May 12	.55	
June 1	.27	3.24	24.5	1.17	.36	.46	May 23	.92	4, C
							May 20	.09	
							May 18	.13	
June 6, 3 p. m.	.25	3.00	29.5	1.41	.47	.04	June 5	.76	4, D
							June 2	.19	
							June 1	1.13	
June 6, 11 p. m.	.19	2.28	20.0	.96	.42	.72	June 5	.76	4, D
							June 2	.19	
							June 1	1.13	
July 18	.35	4.20	44.5	2.13	.51	.76	July 17	.20	4, E
							June 29	.19	
							June 28	.11	

The results of the field measurements and computations for the several watersheds are given in Tables 2 to 7. The watersheds are referred to in the tables by number and the same numbers have been used in referring to the gauging stations of the respective watersheds. The drainage area or watershed area and the time of concentration for the watershed appear in the heading of each table. The time of concentration, as has been explained, is the time required for the water to flow from the farthest point on the watershed to the gauging station. This was determined by noting the time required for the water in the channel at the gauging station to rise from the low to the maximum stage as recorded by the water-stage recorders. This period varied to some extent for the different rains, depending upon the degree of saturation of the watershed at the occurrence of the rain that produced the maximum rate of run-off. Also the time of concentration would be less if the channel were partially filled with water when the rain of greatest intensity occurred, and would be less for rains of high intensity than for rains of less intensity. However, owing to the inability of the recording instruments to register the time with sufficient accuracy, the difference in the time of concentration for the different rains on the same watershed could not be satisfactorily determined, and the time of concentration was taken to be the same for the different rains on the same watershed, with one exception which will be referred to later.

TABLE 3.—*Measurements of rainfall and run-off for watershed No. 3; drainage area, 49.2 acres; time of concentration, 10 minutes*

Date of rain, 1918	Rainfall during time of concentration	Average rate of rainfall during time of concentration	Maximum rate of run-off		Coefficient of run-off (ratio of maximum rate of run-off to average rate of rainfall)	Rainfall prior to period taken as time of concentration	Previous rains over 0.08 inch		See Figure No.
							Date	Amount	
	Inch	*Inches per hour*	*Second-feet*	*Inches per hour*		*Inches*		*Inches*	
Feb. 19	0.24	1.44	33.0	0.67	0.47	0.39	Feb. 15	0.10	3, A
							Feb. 12	.41	
							Feb. 6	.20	
Apr. 16	.34	2.04	42.5	.86	.42	1.17	Mar. 23	.23	3, B
							Mar. 20	.13	
Apr. 28	.52	3.12	72.0	1.45	.46	.09	Apr. 20	.82	3, D
							Apr. 19	1.59	
							Apr. 17	.72	
							Apr. 16	1.55	
May 7	.54	3.24	58.0	1.17	.36	.18	Apr. 28	1.01	3, E
							Apr. 20	.82	
							Apr. 19	1.59	
May 12	.28	1.68	26.0	.52	.31	.10	May 11	.11	4, A
							May 8	.45	
							May 7	1.19	
May 23	.46	2.76	68.0	1.37	.50	.38	May 20	.09	4, B
							May 18	.13	
							May 12	.55	
June 1	.44	2.64	39.0	.79	.30	.28	May 23	.92	4, C
							May 20	.09	
							May 18	.13	
June 6, 3 p. m.	.34	2.04	42.5	.86	.42	.00	June 5	.76	4, D
							June 2	.19	
							June 1	1.13	
July 18	.50	3.00	80.0	1.61	.54	1.41	July 17	.20	4, E
							June 29	.19	
							June 28	.11	

TABLE 4.—*Measurements of rainfall and run-off for watershed No. 4; drainage area, 15.7 acres; time of concentration, 7 minutes*

Date of rain, 1918	Rainfall during time of concentration	Average rate of rainfall during time of concentration	Maximum rate of run-off		Coefficient of run-off (ratio of maximum rate of run-off to average rate of rainfall)	Rainfall prior to period taken as time of concentration	Previous rains over 0.08 inch		See Figure No.
							Date	Amount	
	Inch	*Inches per hour*	*Second-feet*	*Inches per hour*		*Inches*		*Inches*	
Feb. 19	0.22	1.89	6.5	0.41	0.22	0.37	Feb. 15	0.10	3, A
							Feb. 12	.41	
							Feb. 6	.20	
Apr. 16	.34	2.92	13.5	.85	.29	1.19	Mar. 23	.23	3, B
							Mar. 20	.13	
Apr. 28	.44	3.77	15.0	.95	.25	.09	Apr. 20	.82	3, D
							Apr. 19	1.59	
							Apr. 17	.72	
							Apr. 16	1.55	
May 7	.41	3.51	15.5	.98	.28	.18	Apr. 28	1.01	3, E
							Apr. 20	.82	
							Apr. 19	1.59	
May 12	.22	1.89	9.0	.57	.30	.10	May 11	.11	4, A
							May 8	.45	
							May 7	1.19	
May 23	.33	2.83	15.5	.98	.35	.38	May 20	.09	4, B
							May 18	.13	
							May 12	.55	
June 1	.35	3.00	13.5	.85	.28	.38	May 23	.92	4, C
							May 20	.09	
							May 18	.13	
June 6, 11 p. m.	.25	2.14	9.5	.60	.28	.69	June 5	.76	4, D
							June 2	.19	
							June 1	1.13	
July 18	.41	3.51	25.5	1.61	.46	.71	July 17	.20	4, E
							June 29	.19	
							June 28	.11	

TABLE 5.—*Measurements of rainfall and run-off for watershed No. 5; drainage area, 112 acres; time of concentration, 17 minutes*

Date of rain, 1918	Rainfall during time of concentration	Average rate of rainfall during time of concentration	Maximum rate of run-off		Coefficient of run-off (ratio of maximum rate of run-off to average rate of rainfall)	Rainfall prior to period taken as time of concentration	Previous rains over 0.08 inch		Total rainfall for storm period	Total run-off for storm period	Total run-off in per cent of total rainfall	See Figure No.
							Date	Amount				
	Inch	*Inches per hour*	*Second-feet*	*Inches per hour*		*Inches*			*Inches*	*Inch*		
Feb. 19	0.40	1.41	68.0	0.60	0.43	0.39	Feb. 15 Feb. 12 Feb. 6	0.10 .41 .20	0.95	0.48	50.5	3, A and 9, A
Apr. 16	.40	1.41	69.0	.61	.43	.64	Mar. 23 Mar. 20 Apr. 17	.23 .13 .72	1.55	.57	36.8	3, B and 9, B
Apr. 19	.70	[a] 3.50	333.5	2.95	.85	.12	Apr. 16	1.55	1.08	.92	85.2	3, C and 10, A
Apr. 28	.58	2.05	90.0	.80	39	.07	Apr. 20 Apr. 19 Apr. 17 Apr. 16	.82 1.59 .72 1.55	------	------	------	3, D
May 7	.75	2.65	85.5	.76	.29	.18	Apr. 28 Apr. 20 Apr. 19	1.01 .82 1.59	1.31	.39	29.8	3, E and 10, B
May 12	.37	1.31	39.4	.35	.27	.05	May 11 May 8 May 7	.11 .45 1.19	.52	.18	34.6	4, A and 10, C
May 23	.67	2.36	120.5	1.07	.45	.20	May 20 May 18 May 12	.09 .13 .55	.92	.30	32.6	4, B and 11, A
June 1	.59	2.08	70.0	.62	.30	.16	May 23 May 20 May 18	.92 .09 .13	1.14	.37	32.5	4, C and 11, B
June 6, 3 p. m.	.34	[b] 1.20	56.0	.50	.42	.00	June 5 June 2 June 1	.76 .19 1.13	.33	.17	51.5	4, D and 11, C
June 6, 11 p. m.	.34	1.20	66.0	.58	.48	.69	June 5 June 2 June 1	.76 .19 1.13	.71	.35	49.3	4, D and 12, A
July 18	.76	2.68	124.5	1.10	.41	1.21	July 17 June 29 June 28	.20 .19 .11	2.17	.63	29.0	4, E and 12, B

[a] Time of concentration for this rain taken as 12 minutes.

[b] Rain fell in 10 minutes.

In the first column of Tables 2 to 7 are given the dates of the most intense rains that occurred during the year 1918. In column 2 is given, for each rain, the amount of rain that fell during the time of concentration, from which were computed the values given in column 3, which are the average rates of rainfall, in inches per hour, during the time of concentration. In columns 4 and 5 are shown the maximum rates of run-off in cubic feet per second and in inches per hour. Columns 7, 8, and 9 contain rainfall data, from which an idea can be formed as to the degree of saturation of the watershed. In column 7 is given the amount of rain that fell at the beginning of the storm—that is, prior to the period taken as the time of concentration. Columns 8 and 9 show the dates and amounts of previous rains each of which exceeded 0.08 inch, that contributed to the saturation of the watershed. In column 6 are given the coefficients of run-off or the ratios of the average rates of rainfall during the time of concentration to the maximum rates of run-off. These are the coefficients C for use in the formula $Q = CIA$, which is employed in the rational method

TABLE 6.—*Measurements of rainfall and run-off for watershed No. 6; drainage area, 1.25 acres; time of concentration, 1½ minutes*

Date of rain, 1918	Rainfall during time of concentration	Average rate of rainfall during time of concentration	Maximum rate of run-off		Coefficient of run-off (ratio of maximum rate of run-off to average rate of rainfall)	Rainfall prior to period taken as time of concentration	Previous rains over 0.08 inch		See Figure No.
							Date	Amount	
	Inch	*Inches per hour*	*Second-feet*	*Inches per hour*		*Inches*		*Inches*	
Feb. 19	0.07	2.8	2.04	1.62	0.58	0.39	Feb. 15	0.10	
							Feb. 12	.41	3, A
							Feb. 6	.20	
Apr. 16	.13	5.2	3.09	2.45	.47	1.23	Mar. 23	.23	
							Mar. 20	.13	3, B
Apr. 28	.13	5.2	3.88	3.08	.59	.09	Apr. 20	.82	
							Apr. 19	1.59	
							Apr. 17	.72	3, D
							Apr. 16	1.55	
May 7	.10	4.0	2.27	1.80	.45	.18	Apr. 28	1.01	
							Apr. 20	.82	3, E
							Apr. 19	1.59	
May 12	.07	2.8	.92	.73	.26	.11	May 11	.11	
							May 8	.45	4, A
							May 7	1.19	
May 23	.10	4.0							4, B
June 1	.10	4.0	1.76	1.40	.35	.50	May 23	.92	
							May 20	.09	4, C
							May 18	.13	
June 6, 3 p. m.	.10	4.0	1.38	1.10	.28	.06	June 5	.76	
							June 2	.19	4, D
							June 1	1.13	
June 6, 11 p. m.	.07	2.8	1.51	1.20	.43	.76	June 5	.76	
							June 2	.19	4, D
							June 1	1.13	
July 18	.14	5.6	3.36	2.67	.48	.76	July 17	.20	
							June 29	.19	4, E
							June 28	.11	

TABLE 7.—*Measurements of rainfall and run-off for watershed No. 7, drainage area, 2.79 acres; time of concentration, 3 minutes*

Date of rain, 1918	Rainfall during time of concentration	Average rate of rainfall during time of concentration	Maximum rate of run-off		Coefficient of run-off (ratio of maximum rate of run-off to average rate of rainfall)	Rainfall prior to period taken as time of concentration	Previous rains over 0.08 inch		See Figure No.
							Date	Amount	
	Inch	*Inches per hour*	*Second-feet*	*Inches per hour*		*Inches*		*Inches*	
Apr. 16	0.24	4.8	3.20	1.14	0.24	1.23	Mar. 23	0.23	
							Mar. 20	.13	3, B
Apr. 28	.26	5.2	5.03	1.79	.34	.09	Apr. 20	.82	
							Apr. 19	1.59	
							Apr. 17	.72	3, D
							Apr. 16	1.55	
May 7	.18	3.6	2.93	1.04	.29	.18	Apr. 28	1.01	
							Apr. 20	.82	3, E
							Apr. 19	1.59	
May 12	.12	2.4	1.18	.42	.18	.11	May 11	.11	
							May 8	.45	4, A
							May 7	1.19	
May 23	.15	3.0	2.42	.86	.29	.38	May 20	.09	
							May 18	.13	4, B
							May 12	.55	
June 1	.17	3.4	2.42	.86	.25	.50	May 23	.92	
							May 20	.09	4, C
							May 18	.13	
June 6, 3 p. m.	.17	3.4	1.81	.64	.19	.04	June 5	.76	
							June 2	.19	4, D
							June 1	1.13	
June 6, 11 p. m.	.12	2.4	1.85	.66	.28	.76	June 5	.76	
							June 2	.19	4, D
							June 1	1.13	
July 18	.24	4.8	4.35	1.55	.32	.76	July 17	.20	
							June 29	.19	4, E
							June 28	.11	

of computing storm water flow. In column 10 of Tables 2, 3, 4, 6, and 7, and in column 13 of Table 5 are given references to the rainfall charts for each of the rains. These charts convey an idea as to the uniformity of the rate of rainfall during periods of intensity.

In columns 10, 11, and 12 of Table 5 are given, for each storm, the total amount of rain, the total amount of run-off, and the percentage of the rainfall that ran off. These data are not given for the smaller watersheds, since their streams are so flashy that the recorders were unable to register with accuracy the changes in the water level.

In Figure 5 is plotted the daily precipitation for the year 1918. The day was taken as beginning and ending at midnight; hence the total amount of rainfall for each rain as given in Table 5 may or may not correspond to the total rainfall given in Figure 5 for the period midnight to midnight, since, for instance, a rain may have begun slightly before midnight and continued into the next day. Such a rain would be recorded in Table 5 as occurring on the day the maximum rate of run-off occurred. Furthermore, where more than one rain

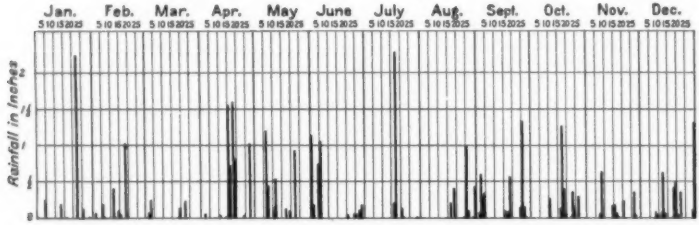

FIG. 5.—Record of daily precipitation from midnight to midnight on the Murchison farm for the year 1918

occurred between midnight and midnight (as on June 6) the total for each rain is recorded separately in the table. Figure 5 readily indicates the probable condition of the soil due to prior rains.

WATERSHED NO. 1

Watershed No. 1 is fan-shaped and contains 20.7 acres, 14 per cent of which is covered with timber. As may be seen from Figure 1, the timber consists of four scattered patches. The cleared portion of this watershed has been cultivated for many years, cotton being the principal crop. Figure 6, A, is a view of the watershed taken from the point marked *a* in Figure 1, and Figure 6, B, is a view taken from the rain-gauge station. Numerous deep gullies exist in the cleared area. Unsuccessful efforts have been made to check erosion by the use of hillside ditches. Over a large part of the cleared area there are bare places incapable of producing a crop, due to erosion. During the period of the investigation cotton was growing on a small part of the watershed near the gauging station; the remainder of the land lay idle.

The distance from the farthest point on the watershed to the gauging station is 1,220 feet, and the average fall is 4.89 feet per 100 feet, the fall of the channel at the gauging station is 2.4 feet per 100 feet, and the maximum fall on the steepest hillside of the watershed is 40 feet per 100 feet. Owing to the small percentage of timbered area

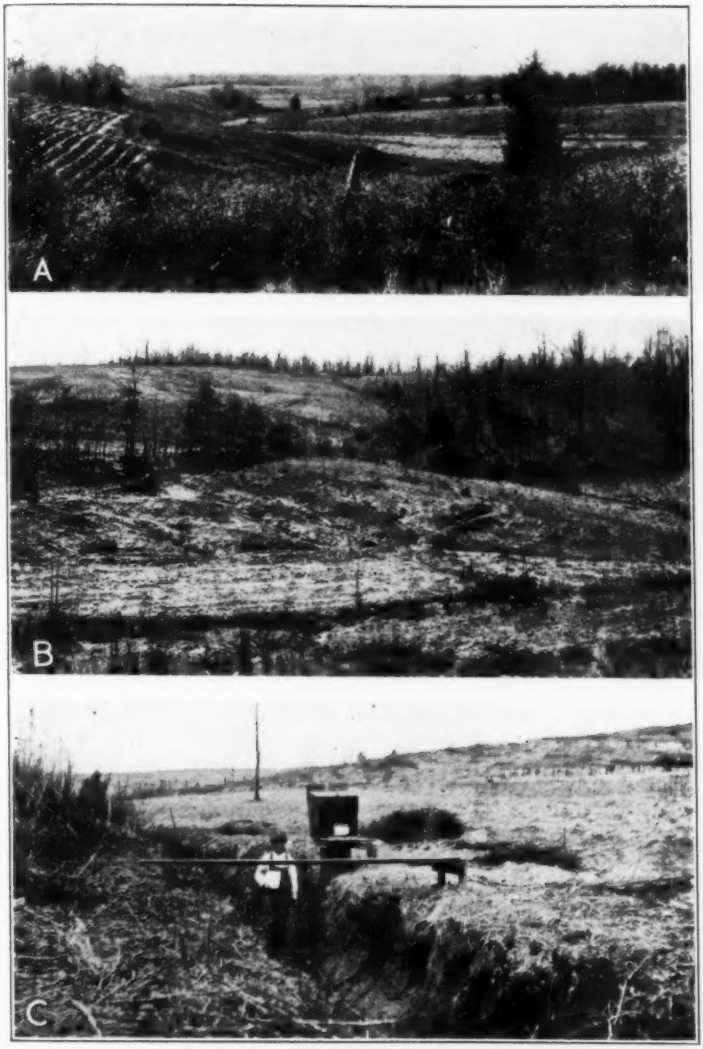

FIG. 6.—A, watershed No. 1 on Murchison Farm, taken from a point marked (*a*) in Figure 1; B, watershed No. 1, taken from rain-gauge station (gauging station No. 1 can be seen at the right); C, channel and gauging station for watershed No. 1

and the numerous gullies which permit a large part of the watershed to drain quickly, the time of concentration for this watershed was found to be small—about 5 minutes—and the rates of run-off comparatively large.

A view of the channel and gauging station is shown in Figure 6, C. This is typical of the gauging stations on the other channels. The gauging bridge consists of a 2-inch plank laid across at right angles to the channel. Figure 7 shows a cross section of the channel at the gauging station. The highest stage in the channel, which occurred on April 19, 1918, and the highest stage resulting from the 10 storms given in Table 2—which stage occurred on July 18, 1918—are shown on the cross section. The rates of rainfall and run-off for these 10 storms are given in Table 2. The highest average rates of rainfall of five minutes duration for the 10 storms given in the table were 4.44 and 4.20 inches per hour and occurred on April 28 and July 18,

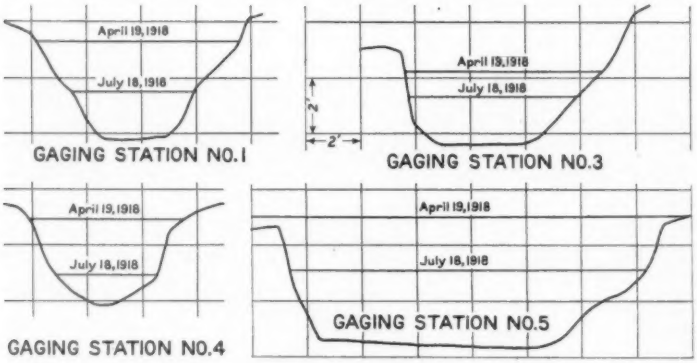

FIG. 7.—Cross sections of channels at gauging stations

respectively. The maximum rates of run-off were 38 and 44.5 cubic feet per second, or 1.82 and 2.13 inches per hour, respectively. It will be noted that the greater rate of run-off occurred for the smaller rate of rainfall. Doubtless this was due largely to the fact that the rain of July 18 was of more uniform intensity for the five-minute period than was the rain of April 28, and also to the difference in the degree of saturation of the soil prior to the intense rates of rainfall. Other factors being the same, one would expect a greater rate of run-off in the spring when there are no growing crops and only scanty vegetation, than in the summer. However, in this case the effect of vegetation was offset by the rain which fell shortly prior to the period of intense rainfall and saturated the vegetation and the ground surface. As may be seen from Table 2, the run-off coefficients for these rains are 0.41 and 0.51, respectively, and the coefficients range from 0.33 to 0.51 for the 10 rains given in the table. A study of the rainfall charts in Figures 3 and 4, and of the data on previous rains given in the table, will reveal in many cases the causes of the variations in the run-off coefficients.

WATERSHED NO. 3

Watershed No. 3 contains 49.2 acres, of which 24.7 per cent is covered with timber. It includes watersheds Nos. 1 and 2, and the

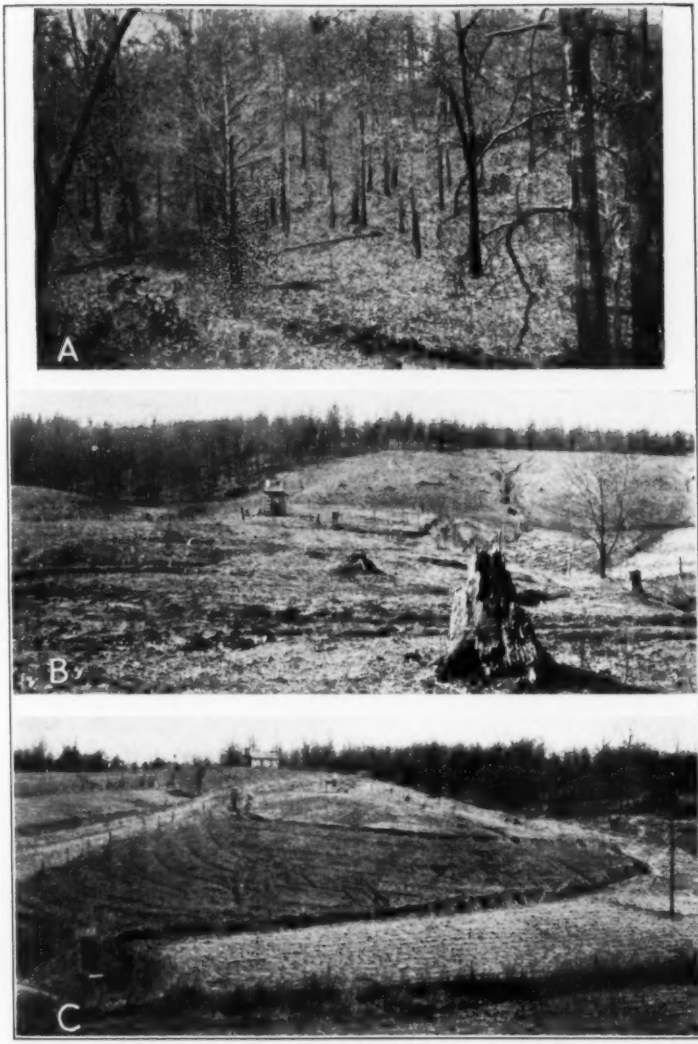

FIG. 8.—A, timbered hillside on watershed No. 2 (note the covering of leaves on the ground); B, hillside on lower portion of watershed No. 3, taken from above rain-gauge station (note the gullies, contour plowing to check erosion, and timbered area on the left of watershed No. 2; C, hillside showing location of rain gauge. This area is part of the lower portion of watershed No. 3 (note the hillside ditches that have developed into deep gullies)

drainage channels of these watersheds unite to form the main channel of watershed No. 3, a short distance above the gauging station. (See fig. 1.) Watershed No. 1 already has been described. Watershed No. 2 contains 20.6 acres, of which 38.8 per cent is timbered. A typical view of a timbered hillside on watershed No. 2 is shown in Figure 8, A. Note the covering of leaves on the ground. Except for a few gullies, the cleared portion of this watershed is comparatively free from erosion. The hilly portion of that part of watershed No. 3 below the junction of the channels of watersheds Nos. 1 and 2 is quite badly gullied and subject to rapid surface washing. (See fig. 8, B and C.) The gullies and the hillside ditches promote the rapid drainage of this portion of the watershed. A view of the lowlands between the hillsides at the lower end of watershed No. 3 is shown in Figure 9, A. A good crop of corn was harvested on this land in 1918. The fall of the channel at the gauging station is 2.2 feet per hundred. The distance from the farthest point on the watershed to the gauging station is 2,152 feet, and the average fall for this distance is 3.99 feet per 100 feet. The maximum fall on the hillsides of the watershed is 64 feet per 100 feet. In Figure 7 is shown a cross section of the channel at the gauging station, with stages for the rains that occurred on April 19 and July 18.

Table 3 gives a summary of the rainfall and run-off measurements for the watershed. The time of concentration for this watershed was taken to be 10 minutes. The maximum rate of run-off for the nine rains listed in the table was 80 cubic feet per second, or 1.61 inches per hour. This was due to a rainfall rate of 3 inches per hour. The rates of rainfall on both April 28 and May 7 were greater but the rates of run-off were less, probably due to the fact that the high rates on those dates occurred near the beginning of the storm, while the maximum rate on July 18 occurred after 1.41 inches of rain had fallen. Referring to Table 3, it is seen that the run-off coefficients for this watershed range from 0.30 to 0.54—practically the same variation as for watershed No. 1—and that the rates of both rainfall and run-off are considerably smaller than for watershed No. 1, as would be expected for the larger area with time of concentration twice that of the smaller watershed.

WATERSHED NO. 4

Watershed No. 4 is fan-shaped and contains 15.7 acres, 38.9 per cent of which is covered with timber. Figure 9, B, is a view of a portion of the watershed. That part of the watershed south of the large timbered area (see fig. 1) is eroded badly. Deep gullies and hillside ditches render it practically impossible to cultivate this land; hence it is used for pasture. Over a large portion of the cleared land on the remainder of the watershed erosion is not so active, and most of this land was in cotton during the period of these investigations. The fall of the channel at the gauging station is 3.5 feet per 100 feet. The distance from the farthest point on the watershed to the gauging station is 1,418 feet, the average fall for this distance being 5.44 feet per 100 feet. The maximum fall on the hillsides of the watershed is 32 feet per 100 feet. Figure 7 shows a cross section of the channel at the gauging station.

Table 4 is a summary of the rainfall and run-off measurements. The time of concentration for this watershed was taken to be seven

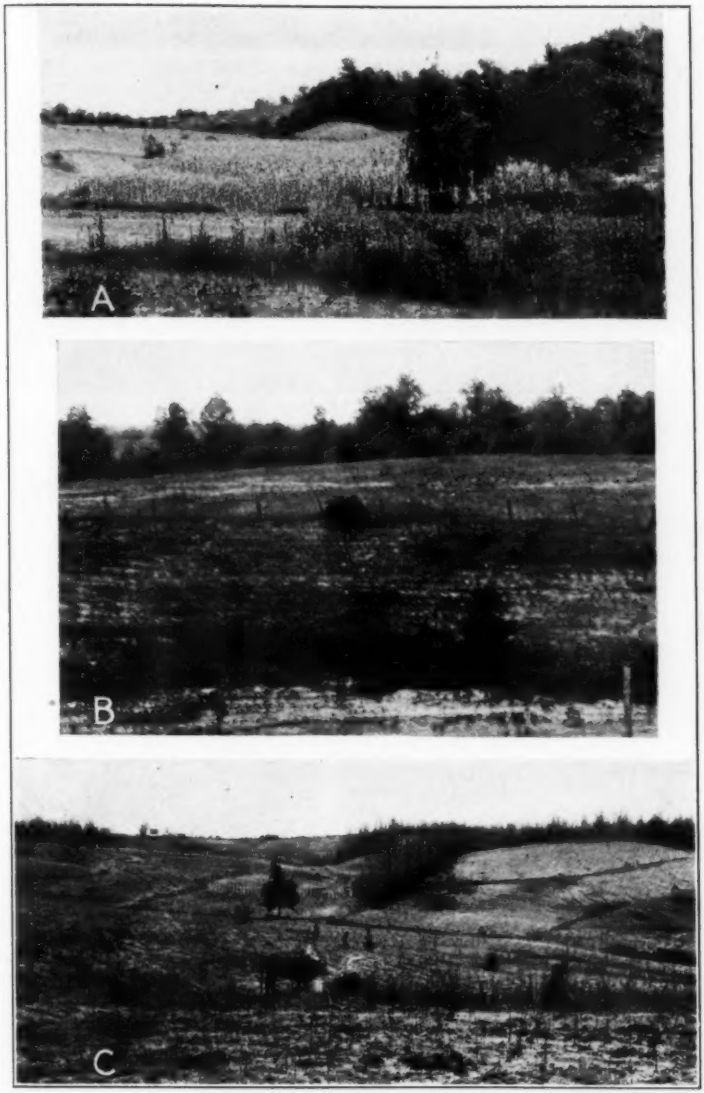

FIG. 9.—A, corn growing on comparatively low land along lower portion of channel of watershed No. 3; B, a portion of watershed No. 4 taken from the rain-gauge station; C, a portion of watershed No. 5 taken from near gauging station No. 6 and looking toward gauging station No. 3

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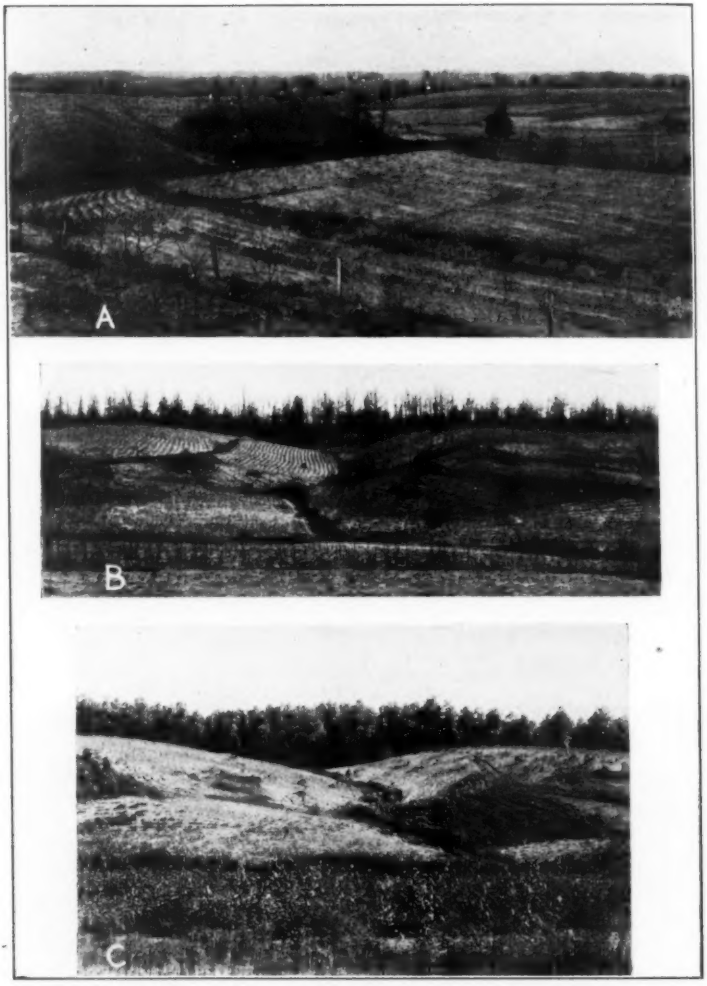

Fig. 10.—A, a portion of watershed No. 5 from rain-gauge station, looking toward gauging station No. 3; B, watershed No. 7, taken in March, 1917; C, watershed No. 7, taken in July, 1917. (Note growth of vegetation)

minutes, which is a little longer than that for watershed No. 1, due no doubt to the greater percentage of timber on watershed No. 4. The run-off coefficients vary from 0.22 to 0.46, and are decidedly lower than the coefficients obtained for watershed No. 1, which fact also is attributed to the greater percentage of timber on the watershed.

WATERSHED NO. 5

Watershed No. 5 contains 112 acres, 23.9 per cent of which is covered with timber. It includes all of the other watersheds that have been described and in addition watersheds Nos. 6 and 7 to be discussed later. From gauging stations Nos. 3 and 4 to gauging station No. 5 (see fig. 1), there is a comparatively wide and flat area of land which constitutes the most fertile and productive part of the watershed. It has been built up by deposits of soil washed from the hilly parts of the watershed during overflows of the main channel. Good yields of corn, cotton, and hay are obtained from this portion of the watershed. Figures 9, C, and 10, A, give views of portions of watershed No. 5.

The distance from the farthest point on the watershed to the gauging station by channel is 3,933 feet and the average fall for this distance is 2.74 feet per 100 feet. The fall of the channel at the gauging station is 1 foot per 100 feet and the maximum fall on the hillsides of the watershed is 64 feet per 100 feet. In Figure 7 is shown a cross section of the channel at the gauging station, upon which are indicated the stages of water in the channel for the most intense rains that occurred. During the heaviest rate of run-off—which occurred on April 19—it is seen that one of the banks of the channel was overflowed.

Table 5 is a summary of the rainfall and run-off measurements. The time of concentration for this watershed was taken to be 17 minutes for all of the rains except that of April 19, for which rain it was taken as 12 minutes, since the average velocity in the channel was greater owing to more rapid filling. The maximum rate of run-off occurred on April 19 and was 333.5 cubic feet per second, or 2.95 inches per hour. The rain of that date fell at the average rate of 3.5 inches per hour for 12 minutes and at the rate of 4.8 inches per hour for 5 minutes of the 12-minute period. (See fig. 3, C.) The run-off coefficient for this rain is 0.85, almost twice as large as for any of the other rains given in the table, which seems to show that the run-off coefficient is considerably higher for excessive rates than for normal rates of precipitation. The next greatest rate of run-off occurred on July 18 and was 124.5 cubic feet per second, or 1.10 inches per hour. The coefficient of run-off for this rain is 0.41. Except only for the rain of April 19, the coefficient of run-off ranged from 0.27 to 0.48.

Computations were made for this watershed to determine, for each rain, the percentage of the total rainfall that ran off. In Figures 11 to 14 are plotted the rates of rainfall in inches per hour for five-minute periods, as well as curves showing the rates of run-off, in inches per hour, due to that rainfall. A common scale of ordinates and abscissas was employed. The area under the run-off curve was reduced to total inches of run-off and this run-off was computed in percentage of the total rainfall. For the heavy rain that occurred

on April 19 this percentage is 85.2, or about the same as the run-off coefficient for that date. However, attention is called to the fact that the run-off coefficient and the percentage of rainfall that runs off are not necessarily the same. The percentage running off during the time of concentration may be greater or less than the percentage running off for the entire storm. The other percentages (see Table 5)

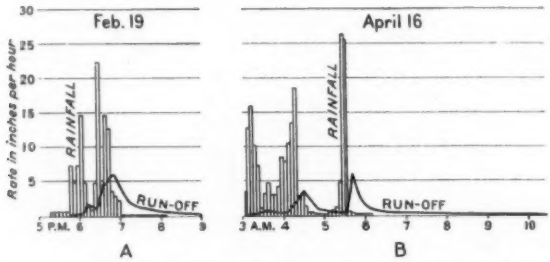

FIG. 11.—Comparative rates of rainfall and run-off, watershed No. 5, February 19 and April 16

range from 29.0 to 51.5. No attempt was made to determine the rates of run-off at the other stations for the rain of April 19, since the stages in the channels were so much higher than for any for which gaugings had been made that only a very rough estimate could be made of the discharges of the channels. It is believed, however, that the results obtained for watershed No. 5, which includes all of the other watersheds, represent in a general way conditions of run-off

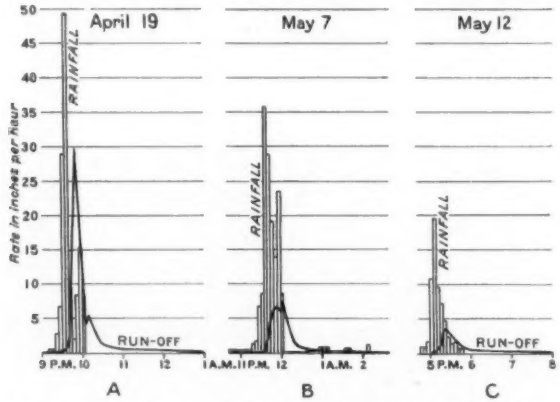

FIG. 12.—Comparative rates of rainfall and run-off, watershed No. 5, April 19, May 7, and May 12

on the other watersheds for this rain. An idea can be obtained from Figures 11 to 14 as to the time relation existing between the maximum rates of rainfall and the maximum rates of run-off. The areas under the rainfall and run-off curves are proportional to the total rainfall and run-off, respectively, so that the relation between the total rainfall and the total run-off for any of the rains can be approximately determined from an inspection of the curves.

WATERSHED NO. 6

This watershed contains 1¼ acres and is the smallest of the several watersheds studied. All of it is cleared and has in time past been in cultivation. However, it has become so badly eroded and barren of soil that it has practically been abandoned to the growth of weeds. The watershed is fan-shaped and the numerous gullies converge

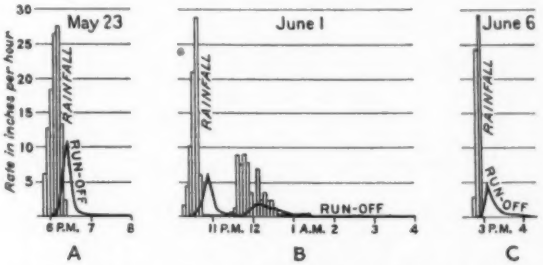

FIG. 13.—Comparative rates of rainfall and run-off, watershed No. 5, May 23, June 1, and June 6

toward the outlet—conditions favorable to a high rate of run-off. The distance from the farthest point on the watershed to the gauging station is 359 feet and the average fall for this distance is 9.78 feet per 100 feet. The maximum fall on the watershed is 33 feet per 100 feet. The time of concentration was judged to be about 1½ minutes, but it was impossible to determine the time accurately from the records of the water-stage recorder.

Table 6 is a summary of the rainfall and run-off measurements. The maximum rate of run-off occurred on April 28 and was 3.88

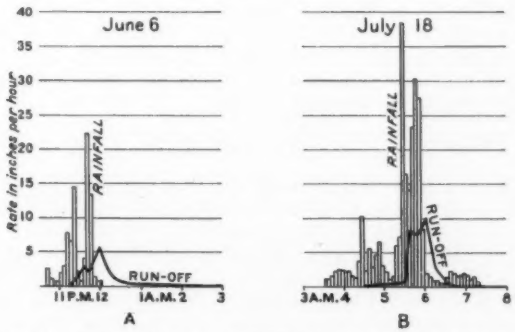

FIG. 14.—Comparative rates of rainfall and run-off, watershed No. 5, June 6, and July 18

cubic feet per second, or 3.08 inches per hour. The maximum average rate of rainfall for this day was 5.2 inches per hour. The run-off coefficients for the 10 rains given in the table range from 0.26 to 0.59.

Measurements of the discharge for this watershed were made with a weir box, as has been described. A catch basin, consisting of the enlargement of the ditch above the weir box was provided to remove

the sand and silt from the run-off water. For the heaviest rains, however, this basin usually was nearly filled and sand was deposited in the weir box, which rendered the weir measurements somewhat inaccurate.

WATERSHED NO. 7

Watershed No. 7 contains 2.79 acres, of which 55½ per cent is covered with timber. Figure 10, B and C, gives two views of this watershed, one taken in March and the other in July. The timber lies on the upper part of the watershed. The lower part, which is cleared, is trough-shaped. Hillside ditches on both of the side slopes intercept the water from the upper portions of the slopes. These slopes are somewhat eroded, as may be seen by a close inspection of Figure 10, B and C, but not as much as are the slopes on watershed No. 6. The cleared portion of this watershed was not cultivated during the period of these investigations. The distance from the farthest point on this watershed to the gaging station is 672 feet, and the average fall for this distance is 8.53 feet per 100 feet. The maximum fall on the slopes of the watershed is 39 feet per 100 feet. The time of concentration was estimated to be three minutes, or twice as long as that of watershed No. 6.

A summary of the rainfall and run-off measurements for this watershed is given in Table 7. The maximum rate of run-off occurred on April 28 and was 5.03 cubic feet per second, or 1.79 inches per hour. This rate was due to a rainfall at the rate of 5.2 inches per hour. The run-off coefficient for this rain is 0.34 as compared with a coefficient of 0.59 for watershed No. 6 for the same rain. The run-off coefficients for this watershed vary from 0.18 to 0.34, while those for watershed No. 6 range from 0.26 to 0.59. This great difference in the coefficients is no doubt due principally to the timbered area on watershed No. 7 and to the fact that the cleared area on No. 7 was less eroded and cut up with gullies than was watershed No. 6.

Measurements of the discharge from this area were made with a weir box similar to the one used for watershed No. 6 and the results were subject to the same sort of inaccuracies, though in less degree, as were mentioned for watershed No. 6.

EFFECT OF TIMBER UPON RATE OF RUN-OFF

The effect of timber upon the rate of run-off is shown by a comparison of the results obtained for watersheds Nos. 1 and 4, where the timbered areas were 14 and 38.9 per cent of the respective watersheds. In Table 8 it is seen that the run-off coefficients for watershed No. 1, for all rains except that of July 18, range from 0.33 to 0.49, and for watershed No. 4, from 0.22 to 0.35. These values show quite conclusively that timber has a decided influence in reducing the rate of run-off from a watershed. However, the results obtained for the rain of July 18—for which run-off coefficients of 0.51 and 0.46 for watersheds Nos. 1 and 4, respectively, were obtained—tend to show that the effect of timber in reducing run-off is slight when the maximum rate of run-off occurs after considerable rain already has fallen. This is to be explained by the fact that interception and percolation on timbered areas are much greater at the beginning of a rain than later, so that an increasingly greater proportion of the rainfall runs off as the rain continues. The falling rain is inter-

cepted by the trees, and the cover of leaves on the ground, until saturated, absorbs a large portion of the rainfall. On April 28 the average rates of rainfall were greater than on July 18, yet the rates and coefficients of run-off were smaller, being 0.41 and 0.25 as compared with 0.51 and 0.46 for the rains of April 28 and July 18, respectively. However, the rain that fell prior to the time of concentration on April 28 was 0.09 inch for both watersheds, while on July 18 it was 0.76 inch for watershed No. 1 and 0.71 inch for watershed No. 4.

TABLE 8.—*Effect of timber on run-off coefficients for watersheds Nos. 1 and 4; watershed No. 1, 14.0 per cent in timber; watershed No. 4, 38.9 per cent in timber*

Date of rain, 1918	Average rate of rainfall during time of concentration		Coefficient of run-off (ratio of maximum rate of run-off to average rate of rainfall)		Rainfall prior to period taken as time of concentration	
	Watershed No. 1	Watershed No. 4	Watershed No. 1	Watershed No. 4	Watershed No. 1	Watershed No. 4
	Inches per hour	*Inches per hour*			*Inches*	*Inches*
Feb. 19	2.40	1.89	0.40	0.22	0.39	0.37
Apr. 16	3.84	2.92	.33	.29	1.21	1.19
Apr. 28	4.44	3.77	.41	.25	.09	.09
May 7	3.60	3.51	.38	.28	.18	.18
May 12	1.92	1.89	.41	.30	.10	.10
May 23	3.12	2.83	.49	.35	.38	.38
June 1	3.24	3.00	.36	.28	.46	.38
June 6, 11 p. m	2.28	2.14	.42	.28	.72	.69
July 18	4.20	3.51	.51	.46	.76	.71

SOME FACTORS INFLUENCING THE RAINFALL AND RUN-OFF RELATION

A comparative study of the rates of rainfall and run-off for the different storms given in Tables 2 to 7 shows what apparently are unaccountable variations in the run-off coefficients. There are many interdependent factors entering into the relation between rainfall and run-off and it is practically impossible to evaluate all of them accurately. For instance, the effect of previous rains upon the capacity of the ground to absorb water from subsequent rains depends upon the nature and amount of previous rainfall, the interval of time between rains, and the amount of water lost through transpiration and evaporation during this interval. If the maximum rate of rainfall occurs at the beginning of the rain, before the surface of the ground has been thoroughly wetted, the percentage of run-off is less than when the maximum rate occurs some time after the beginning of the rain. A greater percentage of run-off also occurs for heavy than for light rains, an illustration of which is the rain of April 19 on watershed No. 5, when the percentage of run-off was 85.2 as compared with the next highest percentage of 51.5 for the comparatively light rain on June 6 on this watershed. (See Table 5.) For the storm of April 19 the time of concentration was less than for the other storms given in the table, because the ditches filled more rapidly and the average velocity of flow was greater. Nonuniformity in the rates of rainfall during the time of concentration is responsible for considerable variation in the run-off coefficient for the same water

shed. An idea as to the degree of uniformity of the rates of precipitation during the time of concentration can be formed from a study of the rainfall charts shown in Figures 3 and 4.

THE RATIONAL METHOD OF COMPUTING RUN-OFF

In the rational method of computing run-off the various factors influencing run-off are provided for in the formula $Q = C\ I\ A$. C, the coefficient of run-off, is the composite effect of all factors influencing run-off which have been mentioned. I, the rate of rainfall to be provided for, depends upon the intensity for different durations of rainfall for the particular locality, and the duration to be used for any particular watershed is equal to the time of concentration of that watershed. Thus the time of concentration takes care of such influencing factors as the shape and slopes of the watershed and the arrangement and character of the drainage channels. To a certain extent, also, it takes account of the vegetation on the watershed, since the distance traveled and the velocity of the water depend partly upon these factors.

PROBABLE FREQUENCY OF RAINFALL INTENSITIES

In the design of drainage channels for small watersheds it is important to know not only the rates of precipitation to be expected for short periods of time but also the probable frequency of the occurrence of these rates. For most improvements it would be impracticable to make provision for the greatest rates of rainfall ever recorded. A matter for the engineer to decide, then, relates to the frequency with which it is permissible that the improvement be overtaxed—that is, whether he shall plan to provide for such intense rates of rainfall as occur but once in, say, 50 years, or whether he shall adopt a frequency of 25 years, or 10 years, or 1 year. In reaching his decision the engineer must, of course, take account of all of the interests involved.

The probable frequency of different rates of precipitation for storms of various durations is shown by the curves in Figure 15. These curves were plotted from precipitation data in Table 15 of Meyer's Elements of Hydrology,[5] which data were compiled from the United States Weather Bureau records taken at the following 19 stations, for the period 1896 to 1914: Boston, Albany, Pittsburgh, Elkins, Asheville, Knoxville, Memphis, Cairo, Indianapolis, Cincinnati, Cleveland, Detroit, Grand Haven, Chicago, Madison, St. Paul, Moorhead, Yankton, Dodge City. These stations showed similar rates of precipitation and were grouped together for the purpose of indicating the probable frequency of rains during a period of time longer than the periods for which the records were available at each individual station. From these curves the engineer can readily determine what rate of rainfall intensity should be adopted as the basis of his improvement, having first decided with what frequency he would be justified in permitting the capacity of the proposed improvement to be exceeded.

[5] MEYER, A. F., THE ELEMENTS OF HYDROLOGY. 487 p., illus. New York and London. 1917.

APPLICATION OF RESULTS

The results of these investigations are applicable to the design of open-ditch drainage systems, graded-terrace systems, small diversion ditches, storm-water sewers draining in part agricultural areas, tile drains with surface inlets, road culverts, and other improvements required to care for the run-off from small watersheds. It should be understood, however, that for the direct application of these results to specific projects, it is necessary that the nature and characteristics of the watersheds involved be essentially similar to those of the watersheds herein described. To cite an extreme case, it would be incorrect to assume for flat watersheds run-off coefficients identical with those obtained in these investigations on hilly land.

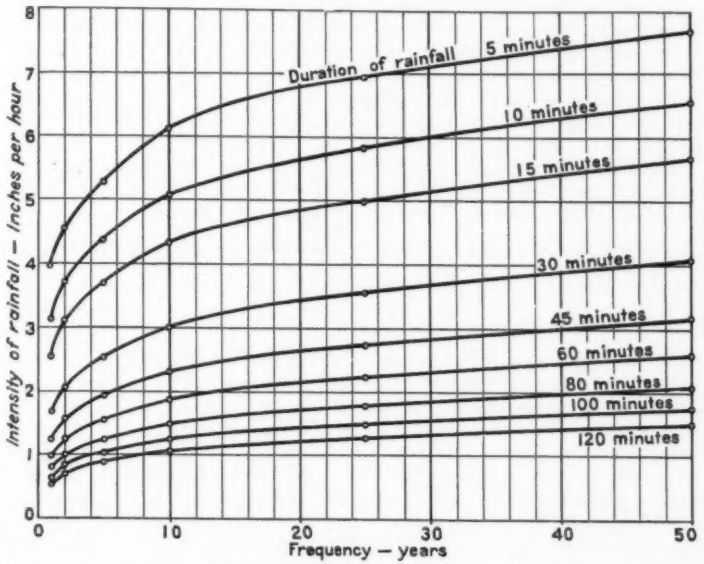

FIG. 15.—Curves showing relation between frequency and intensity of rainfall for storms of various duration

In determining the probable rate of run-off from any particular watershed the rational method should be employed. Values of C, I, and A should be determined for substitution in the equation $Q = C\,I\,A$. A, the watershed in acres, should be determined from a map if available, or from a survey of the watershed. C, the run-off coefficient, should be selected from the experimental values for C given in Tables 2 to 7, such revisions being made as seem necessary to account for differences in characteristics. I, the rate of rainfall in cubic feet per second per acre—for practical purposes this is the rate of rainfall in inches per hour—depends upon the time of concentration for the watershed, and upon the frequency period decided upon. The time of concentration can be determined approximately by measuring the distance and estimating the average velocity from the most remote point to the outlet of the watershed, by channel.

Where the proposed improvement consists simply of a drainage ditch, occasional overflows of which would do little harm, it may be sufficient to make provision for such heavy rains as occur but once or twice a year. In the case of a road culvert through an expensive hard-road embankment it may be advisable to provide for such rains as have a frequency of once in 20 or even 50 years.

After determining the time of concentration and deciding upon the probable frequency of the rain to be provided for, the rate of rainfall that applies can be determined from the curves in Figure 15. For instance, if the time of concentration is 10 minutes and provision is to be made for the greatest rain that occurs once in four years, then the curve "10 minutes" gives that rate of rainfall as about 4.2 inches per hour.

As an example, let it be required to estimate the rate of run-off to be provided for in a channel in Tennessee draining a watershed area of 28 acres with characteristics similar to those described for watershed No. 1. The distance by channel is 1,800 feet from the most remote point on the watershed to the outlet and it is desired to provide capacity in the channel for such a maximum rate of rainfall as occurs once in two years.

The time of concentration for the watershed may be assumed to be the same as that given in Table 1 for watershed No. 1, namely, 5 minutes. Thus the velocity of flow from the most remote point of watershed No. 1 to the outlet is $\frac{1,220}{5}=244$ feet per minute. Assuming the velocity to be practically the same for the watershed of the proposed channel, then the time of concentration would be $\frac{1,800}{244}=7.38$ minutes, or, say, 7½ minutes. Referring to Figure 15 it is seen from the curves that the maximum rate of rainfall occurring once in two years for a duration of 7½ minutes is about 4.1 inches per hour. This value is found halfway between the 5 and 10 minute curves along the two-year ordinate. Now, referring to the values of C obtained for watershed No. 1, as given in Table 2, it is seen that these values range from 0.33 to 0.51, and for rains with rates of 4.44 and 4.20 inches per hour they are 0.41 and 0.51, respectively. Judging from these data, a value of 0.50 would be satisfactory for this watershed. For the equation $Q=C\ I\ A$ we now have $C=0.50$, $I=4.1$, $A=28$. Making the substitutions we get $Q=0.50\times4.1\times28=57.4$ cubic feet per second as the required capacity of the proposed channel.

FURTHER INVESTIGATION DESIRABLE

As far as the writer knows, these investigations are the first of the kind that have been made to determine rates of run-off in open channels from purely agricultural areas where self-recording instruments were employed. It is fully recognized that the results secured cover merely a small portion of the whole field for investigation, but it is believed that they will prove of considerable value in that small portion and of some value as a dependable guide in the unexplored portion of the field. Excluding mountainous areas, these experiments cover one of the extremes in the topography of watersheds, the opposite extreme being watersheds with very little fall to carry off the water. Between these two extremes lie watersheds

with topography commonly described as slightly rolling, rolling, and moderately hilly. Pending complete investigation of the entire field, fairly accurate estimates can be made for the intermediate types of topography after complete investigations have been made for watersheds of the two extreme types. Of course, many factors besides topography affect the value of the run-off coefficient; all of these should be carefully considered in investigations for comparative purposes in order that the measure of their effects may be more accurately determined as the field covered by the investigation expands.

STRAINS OF KERNEL SMUTS OF SORGHUM, SPHACELOTHECA SORGHI AND S. CRUENTA[1]

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INTRODUCTION

In comprehensive varietal experiments with sorghums in the years 1915 to 1921, inclusive, Reed and Melchers[3] found that milo, feterita, and hegari remained almost free from covered kernel smut, *Sphacelotheca sorghi* (Link) Clinton. In 1923 kernel smut was reported as occurring in milo in northwestern Kansas, northeastern New Mexico, and northwestern Texas.[4] Smutted heads of plants identified as milo were obtained from Colby, Kans., Clovis, N. Mex., and Dalhart and Plainview, Tex. These heads in most cases were only partially smutted.

Plans for investigating the cause of this outbreak of smut in milo were made independently by the Office of Cereal Crops and Diseases and the Kansas Agricultural Experiment Station. Preliminary experiments by the Office of Cereal Crops and Diseases at Arlington Experiment Farm, Rosslyn, Va., in 1923–24 showed that the smut spores from milo produced fairly high percentages of smut in milo. In the autumn of 1924 a limited survey of the infested region in the Southwest revealed kernel smut in fields of both hegari and milo. It was apparent that sorghum mixtures or hybridization in which susceptible parents were involved was not the explanation for the occurrence of smut in commercial sowings of milo and hegari. Following this survey, cooperative investigations were planned by the Offices of Cereal Crops and Diseases and of Dry-Land Agriculture of the Bureau of Plant Industry, United States Department of Agriculture, and the Kansas Agricultural Experiment Station, for the purpose of comparing the smut from milo with the ordinary covered kernel smut of sorghum. A large number of varieties and selections of the various groups of sorghums have been grown in order to compare the pathogenicity of the two smuts and to determine the specific reaction of the various sorghums to the smut from milo. Study was made also of the identity of the milo smut fungus. It is the purpose of this paper to present the results of these investigations.

[1] Received for publication Jan. 26, 1927; issued June, 1927. These data were obtained partly in cooperation with the Kansas Agricultural Experiment Station.

[2] The writers gratefully acknowledge the assistance of C. O. Johnston, R. W. Leukel, and C. H. Ficke in these investigations.

[3] REED, G. M., and MELCHERS, L. E. SORGHUM SMUTS AND VARIETAL RESISTANCE IN SORGHUMS. U. S. Dept. Agr. Bul. 1284, 56 p., illus. 1925.

[4] TISDALE, W. H., MELCHERS, L. E., and CLEMMER, H. J. A STRAIN OF SORGHUM KERNEL SMUT WHICH INFECTS MILO AND HEGARI. (Abstract) Phytopathology 16: 85. 1926.

PRELIMINARY EXPERIMENTS

Seed of milo from several sources, including seeds from partially smutted heads obtained from southwestern fields, was inoculated by dusting thoroughly with spores of the smut from milo, and sown in the greenhouse at Arlington Experiment Farm, Rosslyn, Va., November 15, 1923. Of the 167 plants 5 were smutted. Three of these smutted plants grew from seed obtained from partially smutted heads. A similar experiment was conducted at Arlington Experiment Farm in 1924. Seed of milo from several sources was inoculated with smut from milo collected in different localities and sown in the spring of 1924. The plants grown from this inoculated seed showed high percentages of smutted heads. The results of this experiment are given in Table 1.

TABLE 1.—*Infection of different lots of Dwarf and Standard Yellow milo by kernel smut, Sphacelotheca sorghi, collected from individual heads of milo, kept separately, when grown at Arlington Experiment Farm, Rosslyn, Va., in 1924*

Variety of milo	Source in 1923, of—		Total number of heads	Number of smutted heads	Percentage of smutted heads
	Seed	Smut for inoculation			
Standard Yellow	Clovis, N. Mex. (smutted head)	Not inoculated	219	1	0.5
Do	do	Same head	116	43	37.1
Dwarf Yellow	Colby, Kans. (smutted crop)	Not inoculated	219	5	2.3
Do	do	Clovis	226	56	24.8
Do	Dalhart, Tex.	Not inoculated	269	0	0
Do	do	do	299	0	0
Do	do	do	232	3	1.3
Do	Dalhart, Tex. (smutted head)	do	241	0	0
Do	Dalhart, Tex.	Dalhart	359	60	16.7
Do	do	do	303	35	11.6
Do	do	Plainview	346	55	15.9
Do	Dalhart, Tex. (smutted head)	Same head	154	22	14.3
Do	do	do	162	28	17.3
Do	do	Dalhart	290	82	28.3
Do	Plainview, Tex.	Not inoculated	283	0	0
Do	do	Plainview	305	6	2.0
Do	do	do	257	26	10.1
Do	Plainview, Tex. (smutted head)	Not inoculated	325	0	0
Do	do	Same head	289	102	35.3
Do	do	do	499	46	9.2
Do	Clovis, N. Mex. (smutted head)	Plainview	420	51	12.1

The data in Table 1 show that Standard Yellow and Dwarf Yellow milos are strongly susceptible to the kernel smut from milo when grown under the conditions prevailing at Arlington Experiment Farm.

In the winter of 1924–25 another experiment was conducted in the greenhouse at Arlington Experiment Farm. Seed of several sorghum varieties, including Dwarf Sumac, White milo, Dwarf Yellow milo, Standard Yellow milo, feterita, a broomcorn, and three selections from a cross (Red Amber × feterita) was inoculated, a part with smut from milo, a part with smut from hegari, and a part with the ordinary covered kernel smut from Kansas Orange grown at Manhattan, Kans. The seed was sown January 6, 1925. Feterita and two of the Red Amber × feterita hybrids remained smut free regardless of the source of inoculum. The third selection of Red Amber × feterita showed very low percentages of smutted heads on plants grown from seed inoculated with smut from hegari, broomcorn, and milo, but no smut occurred in the plants grown from seed inoculated with the ordinary kernel smut. The broomcorn smut was collected at Texline, Tex., and may probably be the strain occurring in milo. All smut lots produced fairly high percentages (5.9 to 40 per cent) of smutted heads in broomcorn.

Only smut from hegari and milo produced smut in milo. Of the 15 heads of White milo produced from seed inoculated with smut from hegari, 3 were smutted, while only 3 heads out of 34 were smutted when the seed was inoculated with smut from milo. One head in 11 of Dwarf Yellow milo was smutted when spores from hegari were used and one in 27 when smut from milo was used. Two heads in 18 of Standard Yellow milo were smutted when spores from hegari were used. All other plants were smut free. These records seemed to indicate that the smut from hegari is more pathogenic on milo than is the smut from milo itself, but this conclusion would have to be verified by further work. The smut from hegari produced no smut in Dwarf Sumac, however, while all other smut lots produced from 14.3 to 63.6 per cent of smut in this variety.

VARIETAL EXPERIMENTS IN 1925 AND 1926

In the spring of 1925 sowings were made in the cooperative varietal experiment. The object of this experiment was to grow representative varieties of the important groups of sorghums so as to note their reaction to infection by the smut from milo as compared with their reaction to the covered kernel smut commonly occurring in sorghum. In addition to the varieties, several hybrids which had been bred for smut resistance were included.

Smut for these experiments was collected at Dalhart, Tex., from milo and hegari and shipped to Washington, D. C., where the smutted heads were ground in a meat chopper and the spores sieved out and used for inoculating the seed. The ordinary covered kernel smut was collected from susceptible sorghums at Manhattan, Kans., where smut on milo does not occur naturally. This spore material was carefully packed and sent to Washington, where the seed was inoculated.

Seed of the various sorghums, furnished by the departments of agronomy and botany and plant pathology of the Kansas Agricultural Experiment Station from smut-free plots, was sent to Washington, where each lot was divided into six equal parts. Three parts of each lot were smutted with milo smut and three with ordinary covered kernel smut. A set of the seed inoculated with each kind of smut was sown at each of three different stations, located at Rosslyn, Va., Dalhart, Tex., and Manhattan, Kans. In order to be positive that it was free from smut spores at the time of inoculation, seed used in 1926 was treated by soaking for 30 minutes in a 1:320 solution of formaldehyde, then washed thoroughly in water, and dried before the inoculum was applied. Sufficient spore material was used to make the seed appear dark in color, which is more than naturally occurs in badly infested seed lots.

The seed was sown in rows sufficiently long to produce 100 plants if the stands were reasonably good. In making the records the total number of heads and the number of smutted heads were recorded. In many rows there were fewer than 100 heads, while in others the number exceeded 100. The smut percentages were calculated on the basis of heads smutted.

The data obtained in these experiments are given in Table 2. No attempt was made to strike averages, as only two years' data are available and the higher percentage of infection seems more nearly to represent the potential susceptibility of a variety than does the average.

The data in Table 2 show that the sorghums previously known to be susceptible to covered kernel smut are about equally susceptible to both the strains of smut used, namely, the special strain from milo and hegari and the ordinary strain of covered kernel smut. The sorgos, kafirs, kaferitas, broomcorns, kaoliangs, and the miscellaneous varieties, with the exception of White Yolo, fall into this division.

TABLE 2.—*Reaction of varieties and hybrids of sorghum to infection by a strain of kernel smut occurring on milo, and by the ordinary covered kernel smut, Sphacelotheca sorghi, when grown at Rosslyn, Va., Dalhart, Tex., and Manhattan, Kans., in 1925 and 1926*

Group and variety, strain, or selection	Kansas plot No. or nursery row No. (1924), from which seed was taken	Percentages of infection on sorghum grown from seed inoculated with—											
		Ordinary covered kernel smut						Smut strain from milo					
		Rosslyn, Va.		Dalhart, Tex.		Manhattan, Kans.		Rosslyn, Va.		Dalhart, Tex.		Manhattan, Kans.	
		1925	1926	1925	1926	1925	1926	1925	1926	1925	1926	1925	1926
Sorgo:													
Dwarf Sumac	Plot 4	23.5	19.2	50.0	10.1	26.2	43.1	9.0	11.9	40.6	15.8	14.9	25.6
Fielding Sumac	Plot 3	23.3	28.5	60.8	83.1	48.6	55.6	19.8	7.1	9.5	24.1	27.4	44.3
Red Amber	Plot 31	9.9	15.6	18.4	10.2	10.3	7.0	7.1	12.0	11.0	6.2	24.4	15.0
White African	Plot 10	28.3	23.2	39.7	40.7	45.1	32.0	26.2	8.7	56.4	21.6	42.7	43.6
Kansas Orange (head selection)	Field	2.2	20.0	40.7	7.9	18.8	15.5	1.0	1.6	27.0	11.3	6.3	5.2
Lasley	Row 314	0	11.7	14.4	8.5	26.2	50.0	0.9	8.1	5.7	16.4	6.9	44.9
Kansas Orange, black glumes	Plot 1	3.6	19.1	45.9	0	33.0	17.4	4.1	10.0	26.5	0	10.8	14.0
Leoti Red, F. C. I. 6610		10.3	14.8	11.8	22.8	11.5	23.6	24.0	26.5	19.9	24.1	19.6	10.9
Red Amber × feterita, F_7 hybrids:													
Selfed selection	Row 12	0	0	0	0	0	0	0	0	7.4	1.4	0	14.7
Head selection	Row 18	0	0	0	0	0	0	0	0	25.5	1.0	15.6	3.0
Selfed selection	----do	0	0	0	0	0	0	0	0	28.3	2.9	12.1	5.4
Do	Row 13	0	0	0	1.0	0	0	0	0	36.0	8.4	0	10.2
Do	Row 12	0	1.1	5.6	1.4	0	1.1	0	0	0	0	0	0.8
Do	Row 73	0	0	0	0	0	0	0	0	0	0	0	0
Do	Row 69	0	0	0	0	0	0.5	0	0.8	5.1	6.7	4.1	6.7
Do	Row 42	0	0	0	0	0	0.6	0	0	4.3	0	1.4	0.7
Do	Row 40	0	0	0	1.3	2.5	0	0	0	2.0	0	0	0.5
Do	Row 39	1.6	0	0	1.0	24.1	1.6	0	0	3.6	0	0	0.5
Do	----do	0	1.9	0	1.5	9.4	2.4	0	0	4.8	0.8	0	3.1
Do	Row 25	0	0	0	0	0	0	0	0	0	0	0	0
Head selection	Row 69	0	0	0	0	3.9	1.7	1.8	0	15.6	2.8	0	11.0
Selfed selection	Row 57	0	5.2	19.1	29.2	20.2	16.1	0	0.9	4.2	32.9	0	9.0
Do	Row 56	0	0	0	0	0	0	0	0	0	3.1	0	0
Do	Row 66	0	0	0	8.5	0	0	0	0	10.7	17.7	0.9	6.5
Feterita:													
Spur (selfed selection)	Row 201	0	0	0	0	0	0	0	0	0	0	0	0
Red Leaf (selfed selection)	Row 202	0	0	0	0	0	----	0	0	----	----	0	0
Do	----do	----	0	0	0.5	0	7.7	----	0	0	0	0	0
C. I. 182–1		0	0	0	0	0.5	0	0	0	0	0	0	0
Selfed selection	Row 210	0	0	0	0	0	0	0	0	0	0	0	0
Hybrid, F. C. I. 8926		----	0	----	----	----	4.8	----	0	----	----	----	0
S. P. I. 51989 (1921 seed)		----	0	----	----	----	----	----	0	----	----	----	----
S. P. I. 51989 (1920 seed)		----	0	----	----	----	----	----	0	----	----	----	----
S. P. I. 51991 (1920 seed)		----	0	----	----	----	----	----	0	----	----	----	----
S. P. I. 51989 (1925 seed)		----	0	----	----	----	0	----	0	----	----	----	0
S. P. I. 51991 (1925 seed)		----	0	----	----	----	1.9	----	0	----	----	----	0
Kafir:													
Reed	Plot 14	9.2	12.3	34.0	7.1	23.8	41.3	9.3	8.1	49.2	16.3	23.8	20.6
Pink	Plot 20	15.8	22.7	20.3	21.1	26.0	61.6	13.5	20.9	23.7	13.6	18.5	33.3
Wonder (Bower's)	Row 291	4.6	13.3	37.5	6.8	15.7	47.3	4.3	15.1	30.2	20.8	6.1	40.2
Sunrise	Plot 22	6.5	12.1	40.0	12.0	12.1	32.3	6.3	7.0	36.8	19.8	12.6	31.0
Blackhull	Plot 6	9.2	8.4	12.5	12.6	29.4	45.8	5.8	4.1	33.3	24.4	9.7	20.7
Dawn	Plot 23	8.7	12.9	38.5	26.4	35.5	36.8	6.9	8.0	37.2	16.4	14.7	15.1
Blackhull (head selection)	Field	15.4	9.8	4.3	15.7	21.3	22.6	1.6	6.6	12.7	26.9	5.0	24.6
Red	Plot 19	14.6	8.5	28.6	8.9	46.2	43.9	30.8	5.0	32.8	17.0	21.0	18.4
Pink (head selection)	Field	15.2	12.1	49.0	19.8	37.8	11.6	27.2	10.4	31.9	28.2	4.0	37.6
Wonder (Bower's)	Row 291	7.4	13.2	42.1	14.3	19.2	72.1	6.6	11.8	41.0	10.9	4.5	42.9
Farmer (1923 seed)	Row 401	20.8	10.1	38.9	28.6	27.5	23.8	13.3	2.3	14.3	29.0	25.0	35.7
Dawn (selection Hays Cereal 2421).	----	----	----	----	----	----	22.4	----	----	----	----	----	4.4

TABLE 2.—*Reaction of varieties and hybrids of sorghum to infection by a strain of kernel smut occurring on milo, and by the ordinary covered kernel smut, Sphacelotheca sorghi, when grown at Rosslyn, Va., Dalhart, Tex., and Manhattan, Kans., in 1925 and 1926*—Continued

Group and variety, strain, or selection	Kansas plot No. or nursery row No. (1924), from which seed was taken	Percentages of infection on sorghum grown from seed inoculated with—											
		Ordinary covered kernel smut						Smut strain from milo					
		Rosslyn, Va.		Dalhart, Tex.		Manhattan, Kans.		Rosslyn, Va.		Dalhart, Tex.		Manhattan, Kans.	
		1925	1926	1925	1926	1925	1926	1925	1926	1925	1926	1925	1926
Kafir × feterita:													
F. C. I. 8920	Plot 26	7.9	1.4	35.0	1.6	1.6	8.3	18.7	3.2	41.5	7.7	9.2	10.4
F. C. I. 8929	Plot 28	15.2	4.0	40.5	1.3	9.0	1.7	9.6	5.4	30.8	6.1	15.9	15.1
Hays Cereal 2423			0				0		0				0
Kafir-milo hybrids:													
26-3-1-1, (F_8 Woodward, Okla. 1924)		0	0	2.1	0	2.2	0	0	1.9	22.0	7.8	3.9	31.0
38-1-2-1, (F_8 Woodward, Okla. 1924)			3.8				17.1		5.8				21.0
Smith's, C. I. 808			7.9		14.1		17.1		6.8		13.3		12.1
Dwarf Yellow × Pink, Hays Cereal 244.							3.2						4.1
Dwarf Yellow × Pink, Hays Cereal 257.							0						8.3
Dwarf Yellow × Pink, Hays Cereal 2510.							7.9						10.8
Milo × feterita:													
F. C. I. 8916	Plot 25	1.2	0	13.8	0	4.6	0	1.9	0	9.3	0	0	0
Milo:													
Dwarf Yellow, selfed (very juicy, nonsweet).	Row 6 (Bot.[a])	0	0	0	0	0	0	0	0	12.5	6.1	6.8	17.5
Dwarf Yellow, selfed (juicy, nonsweet).	Row 5 (Bot.[a])	0	0	0	0	0	0	0	0	18.1	4.3	0	17.9
Dwarf Yellow, selfed (juicy, nonsweet).	Row 4 (Bot.[a])	0	0	0	0	0	0	0	0	5.4	3.7	0	8.3
Dwarf Yellow, selfed (extremely juicy and sweet).	Row 3 (Bot.[a])	0	0	0	0	0	0	0	1.9	22.8	11.5	0	26.7
Dwarf Yellow, selfed (extremely juicy and sweet).	Row 2 (Bot.[a])	0	0	0	0	0	0	0	2.2	7.1	6.3	0	12.5
Dwarf Yellow, selfed (pithy, nonsweet).	Row 11 (Bot.[a])	0	0	0	0	0	0	4.5	1.2	15.0	13.4	0	2.5
Standard Yellow, C. I. 234		0	0	0	0	0	0	0	0	27.6	5.0	10.1	12.2
Dwarf Yellow, selfed (pithy, sweet).	Row 9 (Bot.[a])	0	0	0	0	0	0	0	5.3	2.5	1.5	0	14.3
Standard White, C. I. 352		0	0	0	0	0	0	3.5	0	20.6	10.9	16.4	2.9
Dwarf Yellow (pithy, sweet)	Row 8 (Bot.[a])	0	0	0	0	0	0	5.9	3.1	10.3	1.3	0	8.9
Dwarf Yellow, C. I. 332		0	0	0	0	0	0	0	0.7	20.3	3.4	12.1	12.1
Dwarf Yellow (pithy, nonsweet).	Row 12 (Bot.[a])	0	0	0	0	0	0	0	2.4	27.0	9.3	2.5	11.9
Do	Row 10(Bot.[a])	0	0	0	0	0	0	0	0	10.1	10.1	0	13.7
Dwarf Yellow (pithy, sweet)	Row 7 (Bot.[a])	0	0	0	0	3.8	0	0	1.9	16.7	0	0	9.2
Dwarf White, F. C. I. 8929		0	0	0	0	0	0	2.2	1.0	8.7	12.1	9.8	22.9
Dream	Row 351, 1923	0	0	0	2.3	0	0	4.2	1.7	12.6	2.2	9.5	20.9
Fargo Straightneck, C. I. 809			1.1		9.7		0		0		18.9		12.1
Kansas Orange × Dwarf Yellow milo:													
Selfed selection 1, 1925	Row 439						11.7						0
Selfed selection 2, 1925	do						0						4.5
Selfed selection 3, 1925	do						0						5.9
Selfed selection 4, 1925	do						9.0						28.6
Selfed selection 6, 1925	do						4.3						16.7
Selfed selection Remnant, 1924							26.3						50.0
Blackhull × Sourless:													
Selection	Plot 13	15.9	18.7	34.6	21.8	48.4	55.6	20.8	5.8	14.1	27.1	31.3	28.0
Hegari:													
Head selection	Field	0	0	0	0	0	0	2.2	0	17.2	0	0	0
Bulk seed	Plot 18	1.4	0	0	0	0	0	14.1	2.0	46.3	3.1	8.1	0
Broomcorn:													
Standard, C. I. 583		6.0	15.3	11.0	5.3	27.5	5.0	3.5	15.9	4.9	2.9	3.9	2.5
Acme, C. I. 243		13.2	23.8	18.5	9.4	30.8	17.1	17.0	11.0	16.7	2.5	16.5	15.5
Kaoliang:													
Dwarf Shantung, C. I. 293		3.5	24.5	23.4	1.4	8.9	0	4.9	19.2	21.4	4.0	25.9	4.6
Manchu Brown, C. I. 171		1.1	11.1	2.2	0	2.1	3.7	0.9	18.2	5.6	3.2	10.2	9.4

[a] The abbreviation "(Bot.)" refers to the row number in the nursery of the Department of Botany.

TABLE 2.—*Reaction of varieties and hybrids of sorghum to infection by a strain of kernel smut occurring on milo, and by the ordinary covered kernel smut, Sphacelotheca sorghi, when grown at Rosslyn, Va., Dalhart, Tex., and Manhattan, Kans., in 1925 and 1926*—Continued

Group and variety, strain, or selection	Kansas plot No. or nursery row No. (1924), from which seed was taken	Percentages of infection on sorghum grown from seed inoculated with—											
		Ordinary covered kernel smut						Smut strain from milo					
		Rosslyn, Va.		Dalhart, Tex.		Manhattan, Kans.		Rosslyn, Va.		Dalhart, Tex.		Manhattan, Kans.	
		1925	1926	1925	1926	1925	1926	1925	1926	1925	1926	1925	1926
Miscellaneous sorghums:													
White Yolo, Calif. Expt. Sta., 1924.		0	0.8	0	0	0	0	17.2	2.7	77.2	29.5	47.5	57.8
Darso	Plot 15	0	1.1	3.2	6.6	18.4	7.7	4.2	10.0	40.3	20.0	14.7	17.5
White durra, C. I. 81		7.1	14.9	38.3	27.8	53.4	40.4	10.3	15.2	31.3	40.0	31.5	48.3
Shallu, C. I. 85		24.6	12.5	28.7	16.8	73.0	89.9	14.6	0	47.8	40.1	46.6	30.2
Pierce kaferita, selection	Row 395 [b]	0	0	4.5	0	1.8	0	1.6	0	0	0	1.4	5.2
Do	Row 388 [b]	3.8	15.5	18.9	....	27.7	66.1	9.4	7.7	30.6	....	10.0	48.9
Freed Sorgo, head selection	Row 268	1.8	18.8	11.0	16.4	16.1	14.4	3.6	4.7	11.1	29.3	8.6	35.7
Weskan	Row 266	4.7	20.9	19.8	31.6	32.9	60.2	8.0	20.9	13.7	39.0	15.0	51.8
Shrock, selection	Plot 17	16.7	5.4	27.5	2.3	28.8	18.4	27.1	8.1	44.4	5.1	12.4	13.1
Premo, F. C. I. 8929		....	0	....	....	....	1.5	....	4.4	....	....	....	9.1
Chiltex, F. C. I. 8917		....	9.4	....	....	....	11.4	....	12.0	....	....	....	27.1

[b] 1923 seed.

The milos remained very highly resistant to, and most of them were immune from, the ordinary covered kernel smut. This is in agreement with the results of past experiments.[5] The milos were all more or less susceptible to the strain of smut occurring in milo and hegari. Juiciness and sugar content made little difference in the susceptibility of the selections. Yolo behaved very much as milo in that it showed very high resistance to the ordinary covered kernel smut, but proved susceptible to the strain from milo and hegari. It was even more susceptible to this form than most of the milos. The feteritas proved highly resistant to or immune from both strains of smut. In four instances, one at Dalhart and three at Manhattan, infection of feterita by the ordinary covered kernel smut occurred. The few cases in which smut occurred in milo and feterita grown from seed inoculated with the ordinary kernel smut undoubtedly are due to the presence of seed mixtures or natural hybrids. A great many such plants were cut out of the rows in 1925, but a few were still present in 1926. Wherever recognized, these plants were removed before the smut counts were made. A few of them, however, undoubtedly escaped notice. Open-pollinated seed was used in 1925 and self-pollinated seed in 1926. The few off-type plants which were found in the latter year undoubtedly were due to hybridization in previous years. One of the highest percentages of smut occurring in feterita (4.8 per cent) was found in a hybrid, F. C. I. 8926. One of the parents of this variety might have been a susceptible sorghum. In this case segregation might account for the result. It is not at all improbable that more than one strain of smut existed in the collection of the ordinary covered kernel smut, one being pathogenic to certain of the feteritas.

[5] REED, G. M., and MELCHERS, L. E. Op. cit.

Many of the Red Amber × feterita hybrids remained free or almost free from the ordinary strain of covered kernel smut, while a high percentage of them proved susceptible to the milo strain. Only two of these hybrids remained entirely free from both strains at all three stations.

Two of the three kafir × feterita hybrids proved susceptible to both smuts, while the third remained free from both strains at Rosslyn, Va., and Manhattan, Kans., in 1926.

The kafir × milo crosses all proved somewhat susceptible to both smuts. The same is true of the one milo × feterita hybrid. Kansas Orange × Dwarf Yellow milo and Blackhull × Sourless fall into the same class.

The two hegaris reacted in the same way as the milos, being highly resistant to the ordinary covered kernel smut but susceptible to the strain from milo and hegari.

In 1926 covered kernel smut which had been collected in 1921 at Chillicothe, Tex., by H. N. Vinall, on a new importation of feterita (S.P.I. 51989) from Shikaba, Sudan, was used to inoculate seed of a few varieties which was sown at Rosslyn, Va., and Manhattan, Kans. The results of this experiment are presented in Table 3.

The smut from feterita failed to produce smut in the three milos inoculated. Dwarf Sumac and broomcorn proved susceptible. The two feteritas, S. P. I. Nos. 51989 and 51991, became smutted when grown from 1925 seed which was inoculated with feterita smut. The results of tests with this collection of smut indicate that it is a different strain from the other two used in these experiments. Milo smut produced no infection in these varieties at either Rosslyn or Manhattan. Two heads in 106 of feterita, S. P. I. 51991, became smutted at Manhattan when grown from seed inoculated with the ordinary covered kernel smut.

The data in Tables 2 and 3 show that certainly two and probably three strains of covered kernel smut were used. The strain occurring on milo and hegari differs in its pathogenicity from the strain commonly occurring on sorghum, in that it infects milo and hegari about as heavily as it does the hitherto susceptible sorghums. From the meager data available the third strain on feterita appears to differ from the strain on milo in that it does not produce smut in milo but attacks two feteritas which are not smutted by the strain from milo.

TABLE 3.—*Reaction of varieties and strains of feterita, milo, sorgo, and broomcorn to a strain of covered kernel smut from feterita, when the plants were grown from artificially inoculated seed at Rosslyn, Va., and Manhattan, Kans., in 1926*

Group and variety, strain, or selection	Percentage of infection at—	
	Rosslyn, Va.	Manhattan, Kans.
Feterita:		
S.P.I. 51989 (1921 seed)	0	
S.P.I. 51989 (1925 seed)	4.8	5.7
S.P.I. 51991 (1925 seed)	10.8	11.2
Selection (Clovis, N. Mex., 1924)	0	
Milo:		
White (Texas, 1924)	0	
Dwarf Yellow (Texas, 1924)	0	
Selection (Hays, Kans.)	0	
Sorgo:		
Dwarf Sumac (Texas, 1924)	19.7	
Broomcorn (Texas, 1924)	26.3	

MORPHOLOGIC CHARACTERS OF THE STRAINS OF SORGHUM KERNEL SMUT

The fungus causing kernel smut in milo and hegari probably is a strain of covered kernel smut, *Sphacelotheca sorghi*.[6] Considerable difficulty has been experienced in attempting to arrive at a definite conclusion regarding the identity of the organism. Specimens obtained from New Mexico and Texas in 1923 and later years bore some resemblances, both macroscopically and microscopically, to both the covered kernel smut, *S. sorghi* (fig. 1), and the loose kernel smut, *S. cruenta* (Kühn) Potter. The membranes enveloping the smut balls seemed in some cases to be more fragile than those of the covered kernel smut, but resembled somewhat in this respect those of loose kernel smut. A microscopic examination showed that the membranes were composed of two types of sterile cells. The elongated cells of small diameter, adhering in chains when the tissue is macerated, are typical of *S. sorghi*. The spherical cells, with a diameter about twice that of the spores, and adhering rather loosely in clumps or balls, are typical of *S. cruenta*.[7] The specimens from Texas had a predominance of cells of the *sorghi* type (fig. 1), while those from New Mexico seemed to have more of the *cruenta* type of sterile cells. These spherical cells, however, were somewhat smaller, on the average, than the sterile cells found in authentic specimens of *S. cruenta*. Milo grown on Arlington Experiment Farm in 1924 from seed inoculated with spores from New Mexico and Texas contained fairly high percentages of smut (Table 1). An examination of smut galls from these plants at the time the normal kernels were in the milk stage revealed only the elongated chainlike cells of the *S. sorghi* type, regardless of the source of the inoculum. After the plants were mature both types of sterile cells were found in the smut balls. An examination of authentic specimens of both loose and covered kernel smut revealed both types of sterile cells in almost every collection examined. The type supposedly characteristic of the given species always predominated. Smutted specimens of milo grown at Arlington Experiment Farm and of milo and hegari collected in New Mexico and Texas were sent to G. P. Clinton, who decided that they were covered kernel smut, *S. sorghi*. He concluded that the spherical sterile cells present were somewhat too small and did not aggregate in balls sufficiently to be typical of *S. cruenta*.

The feterita smut collected by H. N. Vinall in 1921 and used in the experiments in 1926 (fig. 2, A and B) is morphologically very similar to the form on milo and hegari and should be placed in the same species, *sorghi*.

In September, 1926, a field of Dwarf Yellow milo containing 15 per cent of kernel smut was found near Shafter, Calif. This smut (fig. 3, A) with the exception of one head (fig. 3, B) was typical of the smut occurring on milo in New Mexico and Texas (fig. 1). The one head mentioned above was more typical of the loose kernel smut of sorghum than of that occurring on milo. Some of the smut galls were very long. In some cases they reached a length of about 1.5 cm. (fig. 3, B). The columella was long and rather pronounced. The enveloping membranes were somewhat more fragile than those of covered kernel

[6] TISDALE, W. H., MELCHERS, L. E., and CLEMMER, H. J. Op. cit.
[7] POTTER, A. A. THE LOOSE KERNEL SMUT OF SORGHUM. Phytopathology 5:149–154, illus. 1915.

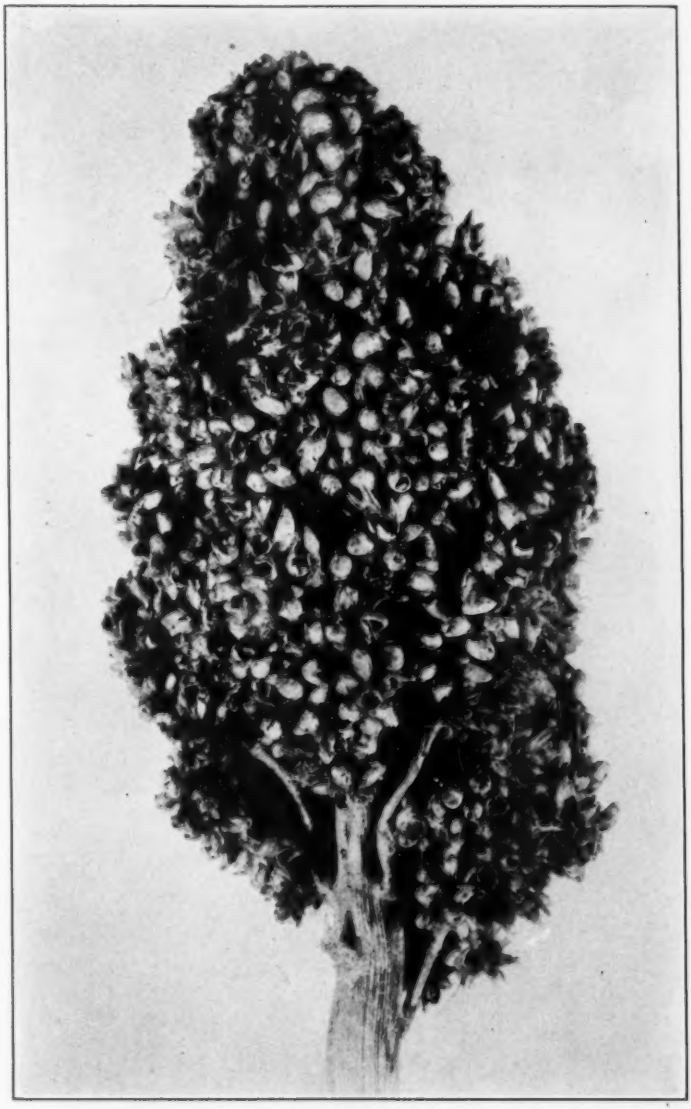

FIG. 1.—Kernel smut of Dwarf Yellow milo, from plant grown at Dalhart, Tex., in 1926. The smut apparently is a strain of covered kernel smut, *Sphacelotheca sorghi*

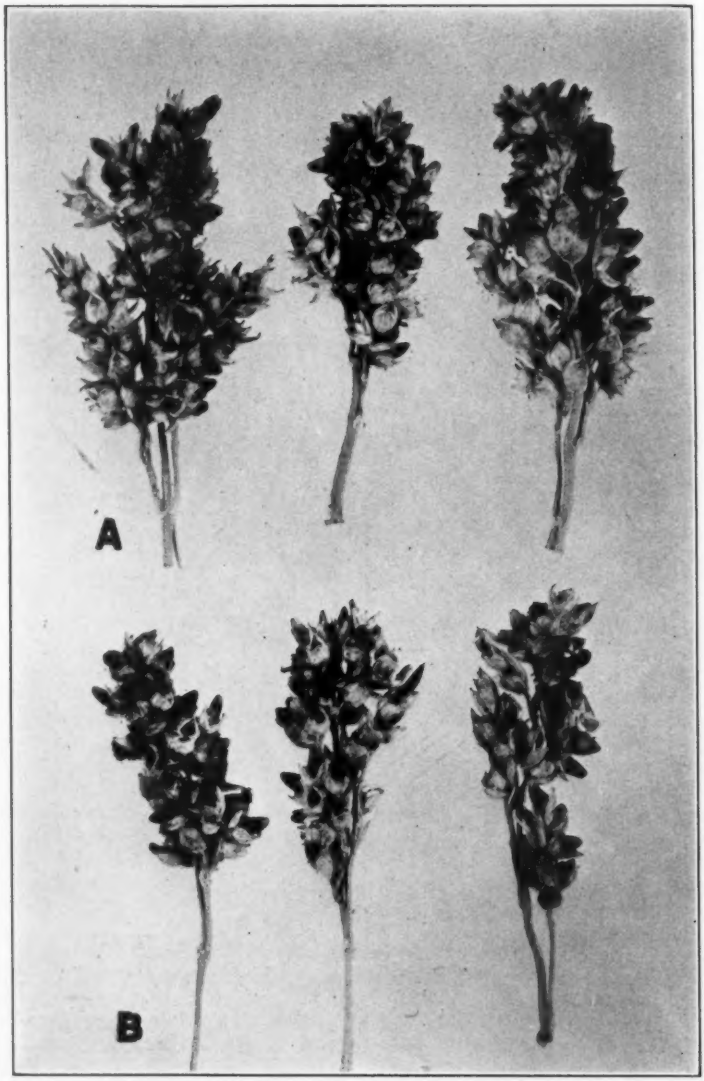

FIG. 2.—Kernel smut, probably a strain of *Sphacelotheca sorghi*, on feterita grown at Arlington Experiment Farm, Rosslyn, Va., in 1926: A, Feterita, S. P. I. 51991; B, Feterita, S. P. I. 51989

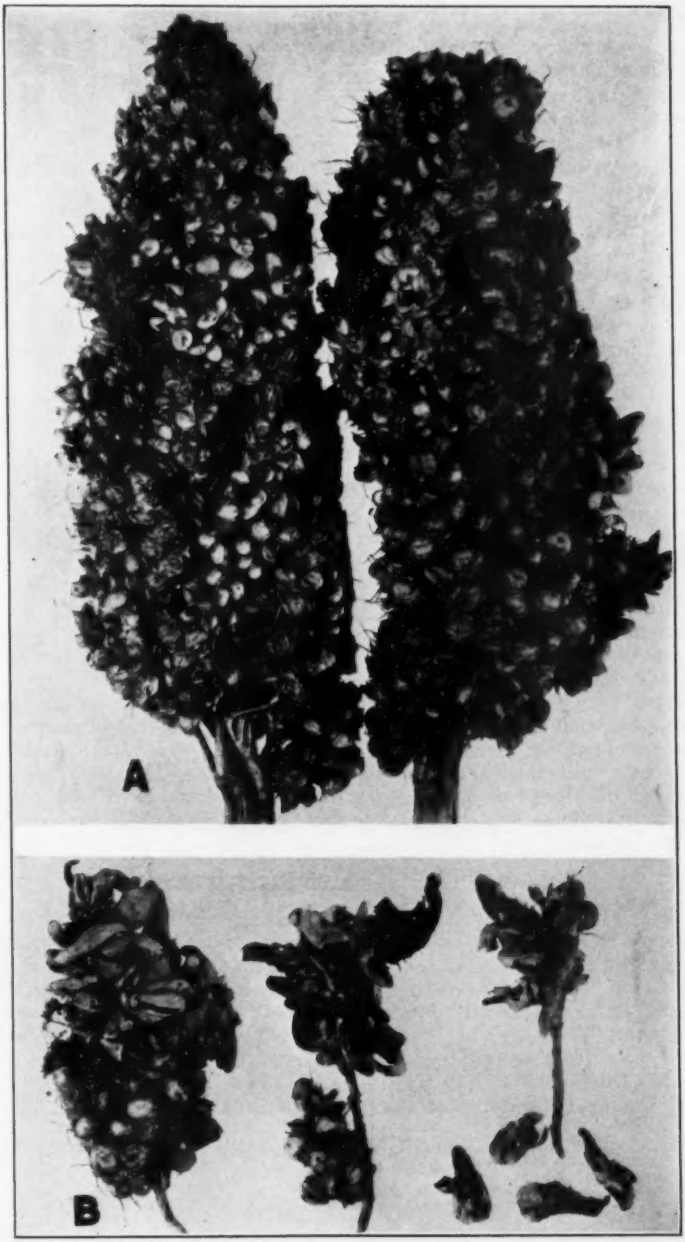

FIG. 3.—Kernel smut of Dwarf Yellow milo from different plants grown in the same field at Shafter, Calif., in 1926. These probably are variants within the strain of *Sphacelotheca sorghi*, which causes smut in milo and hegari: A, external characters typical of covered kernel smut, *S. sorghi*; B, external characters more like those of loose kernel smut, *S. cruenta*

smut, but not nearly so fragile as the membranes of loose smut. Both types of sterile cells were present, with the elongated chain-like *sorghi* type slightly predominating.

There seems to be more than one possible explanation for the occurrence in milo, hegari, and feterita of what appears morphologically to be intermediate stages between the two smut species, *Sphacelotheca sorghi* and *S. cruenta*.

In the first place, the peculiar strains of smut may represent hybrids between the two species. It is conceivable that a single sorghum plant might be infected by both fungi and that fusion might take place between growing hyphae of the two species, resulting in a hybrid fungus which might account for these variations and also for the apparently more virulent nature of the fungus which attacks the hitherto resistant sorghums. Fusion also may have taken place between sporidia of the two species on the surface of the seed and the resulting hypha may have infected the seedling and developed the hybrid form.

In the second place, there may be no sharp line of demarcation between *S. sorghi* and *S. cruenta*, as the descriptions in literature indicate. If a large number of collections of kernel smut were made from a large number of host varieties and under a wide range of climatic conditions throughout the world, it might be found that what has been described as two species simply represents the extremes in a series of variants. The strains in milo and feterita may represent hitherto unrecognized intermediates in such a series.

In the third place, these morphological variations from *S. sorghi*, the more closely related species, may be due to reactions of the particular host on the fungus. Busse[8] has stated that certain characteristics of the covered kernel smut are different on different host varieties. Potter[9] found the same to be true of loose smut.[10] They may simply be physiological variants within the species *S. sorghi* which are influenced by the host. This is perhaps the most probable explanation of the peculiarities in the morphology of these strains. While the morphologic differences should receive consideration, emphasis should be placed on the significance and importance of the physiologic differences which are reflected by the pathogenicity of these smut strains.

LOOSE KERNEL SMUT IN FETERITA

In addition to the collection of what appears to be a strain of covered kernel smut in feterita, the results of experiments with which are given in Table 3, J. H. Martin, Associate Agronomist in charge of Grain Sorghum Investigations, Office of Cereal Crops and Diseases, and G. T. Ratliffe, Superintendent of the United States San Antonio (Texas) Field Station, collected several heads of feterita, C. I. 182, from secondary shoots from stubble, which were smutted with kernel smut at San Antonio, Tex., in 1926. According to Ratliffe the heads produced on the primary culms were smut free. These

[8] BUSSE, W. UNTERSUCHUNGEN ÜEBER DIE KRANKHEITEN DER SORGHUM-HIRSE. Arb. K. Biol. Gendht samt., abt. 4: 319-426, illus. 1904.
[9] POTTER, A. A. Op. cit.
[10] REED, G. M., and MELCHERS, L. E. Op. cit.

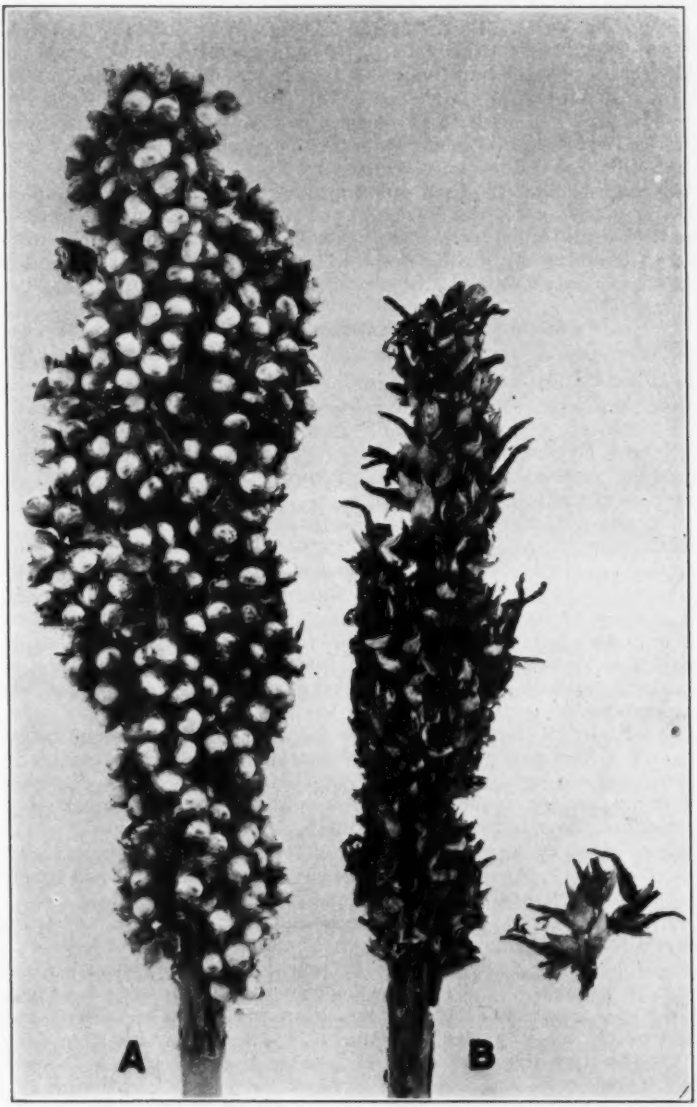

FIG. 4.—Feterita, C. I. 182. Heads from secondary shoots of plants grown at San Antonio, Tex. The primary heads, which were harvested early, were smut free: A, normal head; B, head smutted with loose kernel smut, *Sphacelotheca cruenta*

specimens were typical of the loose kernel smut, *Sphacelotheca cruenta* (fig. 4, B). This is interesting in view of the fact that Reed [11] found feterita to be resistant to both loose and covered kernel smut. The strain of feterita in which this smut was found was not included in his experiments, however. The occurrence of loose smut in feterita may be an indication that it is a special strain of *Sphacelotheca cruenta*, pathogenic on feterita. Again it may mean simply that infection takes place ordinarily when the smut spores are on the seed, but that the fungus is not able to keep pace with the growth of the plant unless the latter be cut back or injured in some other way to cause the production of secondary shoots, which are not able to outstrip the development of the fungus and consequently become visibly infected. Study is needed to clear up some of these points.

SUMMARY

In 1923 kernel smut was found occurring in milo in northwestern Kansas, northeastern New Mexico, and northwestern Texas. The smut also occurred in hegari in the same portions of New Mexico and Texas.

Preliminary experiments conducted in the greenhouse and field at Arlington Experiment Farm, Rosslyn, Va., in 1923 and 1924, showed in some cases high percentages of kernel smut in milo grown from seed inoculated with smut from milo.

Experiments were conducted at Rosslyn, Va., Dalhart, Tex., and Manhattan, Kans., in 1925 and 1926 to determine the reaction of numerous varieties and hybrids of sorghum to infection by the strain of kernel smut occurring on milo, and by the ordinary covered kernel smut of sorghum, *S. sorghi*. These proved that the smut occurring on milo and hegari differs from the ordinary covered kernel smut in that it is pathogenic on milo, White Yolo, and hegari, heretofore resistant sorghums. It also is pathogenic on the sorghums which are susceptible to the ordinary covered kernel smut.

Externally the smut on milo and hegari bears close resemblance to covered kernel smut, *Sphacelotheca sorghi*, although it occasionally is found to have certain of the characteristics of loose smut, *S. cruenta*. In almost every specimen, microscopic examination revealed two types of sterile membrane cells, namely, (1) the elongated cells of small diameter, occurring in chain fashion, typical of the sterile cells of *S. sorghi*, and (2) the spherical cells of larger diameter, grouped together in balls, and typical of the sterile cells of *S. cruenta*.

In all probability, the smut in milo and hegari is a strain of *Sphacelotheca sorghi*, although there may be some possibility that it is a hybrid between *S. sorghi* and *S. cruenta*, resulting from a fusion between hyphae of the two species growing in the same host plant, or the milo smut may be an intermediate in a series of variants ranging from *S. sorghi* as one extreme to *S. cruenta* as the other.

A collection of kernel smut of feterita made by H. N. Vinall in 1921 apparently is a strain of *Sphacelotheca sorghi*, differing in its pathogenicity from the ordinary covered kernel smut and also from the strain in milo and hegari.

Loose kernel smut, *Sphacelotheca curenta*, was found in secondary heads of feterita, C. I. 182, at San Antonio, Tex., in 1926. Feterita hitherto has been free from loose kernel smut.

[11] REED, G. M. VARIETAL RESISTANCE AND SUSCEPTIBILITY OF SORGHUMS TO SPHACELOTHECA SORGHI (LINK) CLINTON AND SPHACELOTHECA CRUENTA (KÜHN) POTTER. Mycologia 15: 132-143, illus. 1923.

ANTHELMINTIC PROPERTIES OF SANTONIN[1]

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INTRODUCTION

In the world of therapeutics certain drugs or preparations have been used for so many years that the statements in the literature, especially in the textbooks and also in articles in professional journals, as to the action of these drugs have a tendency to reiterate impressionistic ideas or traditions. Printed statements are ordinarily copied and passed on with little or no attempt to substantiate the claims made. With a widespread impression once established it is difficult to revise opinions with regard to drugs and a writer is placed in a precarious position if his results conflict with the generally accepted views.

WIDE VARIATIONS IN METHODS OF ADMINISTRATION

Santonin is one of the drugs having an extensive traditional reputation as an anthelmintic. Its use and results have been varied in the hands of the users as reported by them. After many years of use the method of administration and the dose rate of the drug still show wide variations. It is recommended by some persons who have used it as valuable in single-dose treatments and by others as valuable only in divided doses continued over a considerable period. By some it is administered alone as a pure drug and by others combined with one or more substances said to have synergistic value. Some administer santonin simultaneously with a purgative; others regard this as bad practice and prefer to follow it with a purgative several hours after administration, while still others give a purgative both preceding and following the drug. The type of purgative advised is not a matter of uniform opinion, and various substances, such as salines, oils, calomel, and arecoline, have been advocated. Some believe that feed should be withheld from the subject preceding the treatment, while others make no such provision; some administer the preparation mixed in the feed, while others claim that this procedure gives very poor results. Certain workers insist on the necessity of individual treatments, while another group advises its use in flock treatments.

The great safety of santonin has repeatedly been referred to as one of the outstanding qualities of the drug. This is a factor of considerable importance when it is necessary to treat very young or weak animals for intestinal parasitism. However, to be useful, an anthelmintic must combine a fair degree of efficacy and cheapness with reasonable safety.

[1] Received for publication Mar. 19, 1927; issued June, 1927.

SOURCES OF SANTONIN

The differences in results obtained are sometimes attributed to differences in the sources or nature of the santonin used. Recently certain commercial concerns have published the information that "that plant grows only in the wildest part of the Russian steppes, far from any seaport or commercial center, the most important area being the northeastern district of the Province of Turkestan." In this connection it may be noted that the plant from which santonin is obtained has been introduced into the United States and that it appears to thrive well in several semiarid sections of this country. While Turkestan is probably the native home of this plant, the Bureau of Plant Industry has grown it in an experimental way in several sections of the western slope of the United States. This fact, together with the reported increased foreign production, will probably operate to keep the cost of santonin at a reasonable figure in the future. The precise value of the domestic santonin has not been investigated by the writer, and in order to test the drug the Turkestan product was used.

EXPERIMENTAL WORK

A consideration of the writings of various workers shows a considerable divergence of opinion as to the value of santonin. The differences of opinion arise in large part from the fact that no uniform method of testing the drug has been used by investigators and that in only a few cases have accurate counts been made of the worms passed and a critical evaluation made of the results as ascertained by post-mortem examination of the animals treated.

In the present instance an effort has been made to get additional and definite information regarding the efficacy of santonin when used for anthelmintic purposes. A sample of the product with a guaranty of purity was procured from a representative of a firm interested in promoting its use. This was tested for purity in the Biochemic Division, Bureau of Animal Industry, and found to be free from adulteration. In order to get the most complete data possible it was used with and without purgation in varying doses, the drug being placed in hard gelatin capsules for administration. The dogs used in the experiment were confined in separate iron cages, were allowed their customary rations, and were given attention after treatment.

TESTS ON DOGS

First Series

In the first set of experiments with dogs the animals were made to fast for 24 hours and santonin was given in the doses and with the results indicated below:

Dog 1060, weight 28 pounds; 1 grain santonin; worms passed, none; post-mortem, fifth day, hookworms 49, tapeworms 4, whipworms 7.

Dog 1059, weight 38 pounds; 2 grains santonin; worms passed, none; post-mortem, fifth day, hookworms 20, tapeworms 2, whipworms 7.

Dog 1057, weight 40 pounds; 3 grains santonin; worms passed, whipworms 6; post-mortem, fifth day, hookworms 31, ascarids 11, tapeworms 9, whipworms 38.

Dog 1065, weight 35 pounds; 4 grains santonin; worms passed, none; post-mortem, fifth day, hookworms 46.

Dog 1055, weight 33 pounds; 5 grains santonin; worms passed, none; post-mortem, fifth day, hookworms 16, tapeworms 17, whipworms 5.

Dog 1067, weight 39 pounds; 6 grains santonin; worms passed, none; post-mortem, fifth day, hookworms 2, tapeworms 8, whipworms 27.

From a review of these results it is evident that santonin used alone on dogs which have fasted for 24 hours and not followed by a purgative is not effective in the doses given. In only one instance did it show any anthelmintic action and in that case, dog 1057, 6 whipworms were passed and 38 remained. There was therefore an efficacy of 14 per cent against whipworms. Santonin gave no evidence of anthelmintic action in doses of from 1 to 6 grains in dogs harboring hookworms, ascarids, and tapeworms, and failed to remove any whipworms from 4 of the 5 dogs infested. The failure of 3-grain doses to remove ascarids is especially significant.

Second Series

In the following tests the animals were kept without food for 24 hours, and were given santonin and calomel simultaneously in the doses and with the results as shown below:

Dog 1063, weight 10 pounds; 6 grains santonin and 5 grains calomel; worms passed, whipworms 1; post-mortem, seventh day, tapeworms 7, whipworms 1.

Dog 1064, weight 18 pounds; 7 grains santonin and 5 grains calomel; worms passed, whipworms 4; post-mortem, seventh day, hookworms 10, tapeworms 8, whipworms 4.

Dog 1061, weight 35 pounds; 8 grains santonin and 5 grains calomel; worms passed, whipworms 1; post-mortem, seventh day, negative.

Dog 1066, weight 35 pounds; 9 grains santonin and 5 grains calomel; dog vomited first day; worms passed, none; dog died sixth day; post-mortem, no worms; post-mortem changes so extensive at necropsy that ante-mortem pathology could not be ascertained.

Dog 1058, weight 14 pounds; 10 grains santonin and 5 grains calomel; worms passed, whipworms 11; post-mortem, seventh day, hookworms 4, ascarids 1, tapeworms 1. (*Dirofilaria immitis* in heart.)

Dog 1060, weight 41 pounds; 11 grains santonin and 10 grains calomel; worms passed, hookworms 2; post-mortem, seventh day, hookworms 10, ascarids 1 (young), whipworms 5.

Dog 1056, weight 42 pounds; 12 grains santonin and 10 grains calomel; worms passed, whipworms 120; post-mortem, seventh day, hookworms 23, whipworms 8.

In this series of dogs, six of which had worms, santonin with a purgative showed an efficacy, against whipworms, of 100 per cent in two cases, 95 per cent in one case, and 50 per cent in two cases, for the five dogs infested with these worms. In only one instance did it remove any hookworms from the four dogs infested and in this case it expelled 2 of the 12 present, or 17 per cent. No efficacy was indicated in its action against ascarids or tapeworms, in spite of the fact that the doses used, from 6 to 12 grains, are much higher than those usually recommended. The death of one animal, dog 1066,

6 days after dosing can not be ascribed definitely to the treatment, as other dogs receiving the larger quantities were not affected. No symptoms other than a subnormal appetite and apathy were observed in this dog.

Third Series

In the next series of tests an ounce of castor oil was given in the morning 15 hours after a dose of santonin administered the previous evening. The dogs had fasted 24 hours. The results of this test follow:

Dog 1099, weight 6 pounds; 1 grain santonin; worms passed, none; post-mortem, fifth day, hookworms 4, ascarids 3, tapeworms 23, whipworms 6.

Dog 1098, weight 6 pounds; 2 grains santonin; worms passed, ascarids 7; post-mortem, fifth day, hookworms 2, ascarids 2, tapeworms 12, whipworms 3.

Dog 1085, weight 6 pounds; 3 grains santonin; worms passed, ascarids, 1; post-mortem, fifth day, hookworms 7, ascarids 22, whipworms 87.

Dog 1087, weight 15 pounds; 4 grains santonin; worms passed, none; post-mortem, fifth day, hookworms 31, ascarids 1, tapeworms 5, whipworms 7.

Dog 1070, weight 19 pounds; 5 grains santonin; worms passed, ascarids, 1; post-mortem, fifth day, hookworms 1, tapeworms 16, whipworms 2.

Dog 1103, weight 24 pounds; 6 grains santonin; worms passed, ascarids, 1; post-mortem, fifth day, hookworms 19, ascarids 2, tapeworms 18, whipworms 19.

The result of this test shows that santonin in the doses given followed by castor oil in 15 hours failed to remove any hookworms, tapeworms, or whipworms, and that its action against ascarids was not dependable. In two of the six infested inimals it failed to remove any ascarids and in the other four it was 100 per cent, 77 per cent, 33 per cent, and 4 per cent effective, respectively. These findings can not be correlated with the quantities given.

Fourth Series

The same dose of santonin was given to the dogs in this test in addition to an increased amount of castor oil (2 ounces) at a shorter interval, 8 hours, the dogs having fasted 24 hours, with results as noted below:

Dog 1083, weight 6 pounds; 1 grain santonin; worms passed, hookworms 5, ascarids 8; post-mortem, fifth day, hookworms 112, ascarids 43, whipworms 8.

Dog 1100, weight 8 pounds; 3 grains santonin; no worms passed; post-mortem, fifth day, hookworms 8, tapeworms 4, whipworms 9.

Dog 1102, weight 13 pounds; 4 grains santonin; no worms passed; post-mortem, fifth day, hookworms, 4.

Dog 1086, weight 23 pounds; 5 grains santonin; worms passed, ascarids, 1; post-mortem, fifth day, tapeworms 3, whipworms 4.

Dog 1104, weight 32 pounds; 6 grains santonin; no worms passed; post-mortem, fifth day, hookworms 41, ascarids 15, tapeworms 5, whipworms 5.

In this group of animals there was no indication that the increased and earlier purgation gave better results. In one out of five animals infested with hookworms it removed 5 of the 117 worms present, or about 4 per cent. In two of the four animals infested with ascarids it was 100 per cent effective, in one case it was 16 per cent effective, and in one it failed completely. It likewise failed to remove any tapeworms from three infested dogs or whipworms from five infested dogs. A consideration of the effect of the treatment in the case of one dog, No. 1084, illustrates the manner in which anthelmintics may be misjudged in the absence of post-mortem examination of test animals. The passage of eight ascarids and five hookworms would be sufficient to convince some observers of a high efficacy of the drug. However, a comparison of the number passed with the total number of parasites present shows an efficacy of only 16 per cent against ascarids, 4 per cent against hookworms, and 0 per cent against whipworms.

SUMMARY OF TESTS ON DOGS

Santonin, without purgation and in doses varying from 1 to 6 grains administered to dogs weighing from 28 to 40 pounds, removed 6 of the 90 whipworms present, or about 7 per cent, but had no effect on the hookworms, ascarids, or tapeworms.

In doses of from 6 to 12 grains administered simultaneously with 5 to 10 grains of calomel to dogs weighing from 10 to 42 pounds, santonin removed 2 of the 49 hookworms, or about 4 per cent, 136 of the 154 whipworms, or 88 per cent, but none of the ascarids or tapeworms.

In doses of 1 to 6 grains, followed by 1 ounce of castor oil administered 15 hours later to dogs weighing from 6 to 24 pounds, santonin removed 10 of the 40 ascarids, or 25 per cent, but had no effect on the hookworms, tapeworms, or whipworms.

In doses of from 1 to 6 grains with 2 ounces of castor oil administered 8 hours later to dogs weighing from 6 to 32 pounds, santonin removed 5 of the 179 hookworms, or 3 per cent, and 14 of the 72 ascarids, or 19 per cent, but none of the tapeworms or whipworms.

TESTS ON SWINE

Two pigs weighing 78 and 81 pounds, respectively, were given 5 grains of santonin each in a light feed after having fasted for 12 hours. Six days later this treatment was repeated. It was not feasible to examine the feces of these animals, but on post-mortem examination 15 ascarids were found in one and 68 ascarids in the other. The dosing of animals by mixing the medicinal agent with the feed has never been regarded as an economical or scientific method of treatment by the skilled veterinarian. Certainly in most cases the efficacy of the drug is lowered by the process.

Following this test three pigs, each weighing between 30 and 40 pounds, were given capsules containing 5 grains of santonin after they had fasted for 24 hours. This was administered in the evening and on the following morning, about 15 hours later, and two hours before the regular mash feed was given, a small quantity of mill feed saturated with water in which 5 ounces of Epsom salt had been dissolved was given them. Purgation resulted and 4 ascarids were

passed during the next two days. Post-mortem examination of the animals one week later showed 59, 8, and 37 ascarids, respectively.

One animal weighing 45 pounds, which had fasted 24 hours, was then given 6 grains of santonin in a capsule, followed in 12 hours with a purge of Epsom salt. Two ascarids were passed following the treatment. Post-mortem examination of the animal on the sixth day showed 45 ascarids present.

To another animal weighing 36 pounds which had fasted 24 hours a dose of 15 grains of santonin in capsule was administered, followed immediately by 10 grains of calomel. The animal passed 16 worms during the three succeeding days. Post-mortem examination on the seventh day showed four ascarids in the small intestine.

SUMMARY OF TESTS ON SWINE

Summarizing the santonin tests on swine it may be stated that the dosage of 5 grains in feed was of little or no value. While there is a possibility that some worms were passed, the retention of 15 and 68 worms after treatment is sufficient to condemn either the drug or the method of administration. Santonin administered in 5-grain doses to animals weighing 30 to 40 pounds after they had fasted 24 hours, followed by a purge in 15 hours, removed 4 worms from a lot of three pigs and left an aggregate of 104 in the lot. A dose of 6 grains administered after a fast of 24 hours and followed in 12 hours by a purge of Epsom salt, proved insufficient for a 45-pound animal, removing only 2 of the 48 worms present. A dose of 15 grains accompanied by 10 grains of calomel administered to a 36-pound pig which had fasted 24 hours, proved most effective, removing 16 of the 20 worms present in the animal.

TEST ON HORSES

Many writers have recommended santonin for freeing horses of worms. One writer states that an animal given the classical carbon bisulphide treatment for bots followed in two weeks with a dose of from ½ to 1½ drams of santonin and an aloetic purge 12 hours later, may safely be pronounced worm free. This procedure was followed, and the maximum dose of 1½ drams was given. Post-mortem examination 8 days later showed a great many Habronema of two species and some *Trichostrongylus axei* in the stomach. The intestine contained many cylicostomes of undetermined species and 132 large strongyles representing three species. Just what worms might have been removed is not known, but since so large a number of different varieties remained after the treatment it was not considered worth while to make further tests. No pinworms were found.

It should be mentioned in passing that the treatment suggested is not in line with what is known about the action of santonin and of carbon bisulphide. Santonin is rated generally as primarily valuable in removing ascarids, but carbon bisulphide has been shown by critical test to be approximately 100 per cent effective in removing ascarids from the horse, in addition to being equally effective in removing bots, which are not affected by santonin. There is, therefore, no point in following carbon bisulphide with santonin. It can be followed to advantage by chenopodium to remove the strongyles, cylicostomes, and pinworms from the large intestine.

CONCLUSIONS

The findings reported by Hall and Foster [2] that santonin in single doses of from 1 to 3 grains gave about 24 per cent efficacy in removing ascarids from dogs, and those of Mote [3] to the effect that a value of 0 to 46 per cent appears to be within the actual range of utility for the drug in removing ascarids from swine, are in substantial agreement with the findings reported in this paper. All critical testing of which the writer is aware shows an anthelmintic value for santonin much below what has been and is now being claimed for it in advertisements and in papers based on impressions gathered solely from seeing worms passed. If accurate data were obtained on the value of santonin as an anthelmintic by systematic post-mortem examination of test animals, much of the misinformation concerning its value could be eliminated.

The ease of administration of santonin is an advantage and may tend to prejudice the minds of users against other drugs more difficult to use in favor of santonin, and while it has value, especially in repeated treatments, it is a very much overrated drug at present. In the opinion of the writer its value is principally that of a drug which does not cause irritation of the gastro intestinal tract and hence is of value for use in repeated doses in cases of gastroenteritis with ascariasis, or in repeated doses for removing whipworms.

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[3] MOTE, D. C. ANTHELMINTIC EXPERIMENTS WITH HOGS. Ohio Agr. Expt. Sta. Bul. 378, pp. 153–182. 1924.

THE OVIPOSITION RATE OF THE GRAPE LEAF HOPPERS [1]

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INTRODUCTION

The oviposition of insects has not yet been subjected to exact quantitative analysis. Ample evidence of this is to be found in the review by Richardson (*6*).[2] Before such an analysis can be profitably undertaken, the environmental factors conditioning productivity must be more clearly isolated. Data permitting such treatment have been obtained in the course of an investigation of embryonic and nymphal development of the grape leaf hoppers conducted at the bureau field laboratory at Sandusky, Ohio. These data are insectary data, and because of the fact that the insectary is of the small screened-cage type common in field work, the insectary thermograph records have been considered adequate for the purpose for which they have been here used.

MATERIAL AND METHODS

Adult grape leaf hoppers were collected in the vineyards and confined, each species separately, in lantern-globe cages approximately 4 inches high by 4 inches in diameter, as shown in Figure 1. Each lot of adults was etherized daily and transferred to a fresh leaf. By making these transfers in the evening, any immediate effect of the ether upon oviposition was minimized, for it had previously been determined that 80 per cent of the eggs are deposited during daylight hours.

The females were counted at the beginning of an experiment and following this at intervals ranging from 5 to 15 days. The number that died each day was small and seldom could be attributed to the ether. The dead hoppers were removed just prior to the daily transfer and the numbers recorded. Theoretically, therefore, the number of hoppers in a recount should equal the original number minus the number dead; actually it was usually less than this, the

[1] Received for publication Feb. 22, 1927; issued June, 1927. This is the first of a series of papers on the grape leaf hoppers. The papers were planned and the data recorded under a consolidated fruit-insect division. Owing to the reestablishment of the tropical and subtropical division, however, the papers are issued by an investigator in this division, although logically they form a part of the deciduous-fruit program. Papers in preparation cover (1) the relation between embryonic development and temperature and (2) the factors which influence the rate of nymphal development. Data have been obtained for a treatment of the distributional synecology and the taxonomic relations of the species. In recording the original data valuable assistance was given by Horace H. Bliss, field assistant, and C. B. Bliss.—A. C. BAKER, *senior entomologist, in charge of tropical and subtropical plant insect investigations.*

[2] Reference is made by number (italic) to "Literature cited," p. 852.

difference representing escaped individuals. When this discrepancy, reckoned as $\frac{\text{number escaped}}{\text{number of days} \times \text{number of survivors}}$, equalled or exceeded 7 per cent, the record was thrown out; the average inaccuracy in the records retained was 2 per cent. In estimating the number of females in a jar each day, the number escaped was evenly distributed over the period between counts. Since all jars in which the number of escaped hoppers exceeded 7 per cent were eliminated, this assumption was probably legitimate. The eggs are concealed under the epidermis of the leaf, and can not be counted. The laying rate is based necessarily, therefore, on the number which hatched, the nymphs being easily visible.

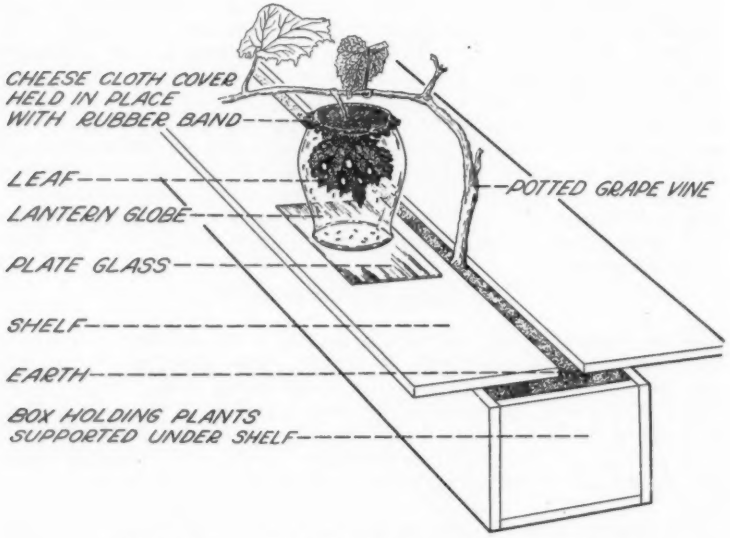

FIG. 1.—Lantern-globe cages used in the experiments with grape leaf hoppers

The adults employed were collected between June 18 and July 5, 1924, in vineyards near Sandusky, Ohio, and consisted largely, if not entirely, of overwintering individuals. The sex ratio, from 7 to 27 per cent males, was the ratio characteristic of the overwintering brood at this season. No mating was observed in any of the cages, nor did there seem to be any difference in laying rate per female per day between cages containing females only and those with the original percentage of males. The males, therefore, have been disregarded in the following analysis.

LAYING RATE

Of the five forms studied, three, *Erythroneura tricincta* Fitch var. *cymbium* McAtee, *E. comes* var. *comes* Say, and *E. comes* Say var. *compta* McAtee, occur commonly on thick-leaved grapes such as the

Concord (*Vitis labrusca*), but are also present in much smaller numbers on the thin-leaved Clinton grape, a variety which is almost pure *V. vulpina*, the native wild grape of the region. The other two species, *E. vitifex* Fitch and *E. vitis* Harris, show the opposite distribution (7). The average laying rates on the two species of grape in the insectary (Table 1) confirmed this specificity of response to host plant.

TABLE 1.—*Mean laying rate of five forms of leaf hoppers on different species of grape, in number of progeny per female per day*

Variety of grape	Species of leaf hopper				
	E. tricincta	E. comes	E. compta	E. vitifex	E. vitis
Concord	1.27±0.06	1.50±0.06	0.87±0.03	0.26±0.05	0.26±0.03
Clinton	.78± .06	.28± .03	.40± .03	1.17± .08	1.48± .11
r	[a].37, .03	[a].22, .41	[a].32, .09		[a].20, .36

[a] Each correlation coefficient, r, between laying rate on Concord and laying rate on Clinton is followed by its corresponding value of *P*, as given by Fisher (1), rather than by its probable error.

This difference in laying rate was quite as marked during the first days in the history of a lot as at the end; the effect of the host plant was immediate and persistent. To a limited extent the variations in laying rate of the same species of hopper on the two species of grape have similar relations to the environment. The correlation coefficients of the laying rate on the thick-leaved grape with the laying rate for the same day on the thin-leaved grape varied from 0.20 to 0.37, but these are of small significance.

In general, the laying rate agrees with the proportionate representation in the field. Except in a small part of Middle Bass Island, Ohio, *compta* is comparatively uncommon, while *comes* and *tricincta*, which proved much more productive in the insectary, are quite generally the dominant forms in the Sandusky region. On wild grapes, *vitis* is uniformly the dominant species, and of the thick-leaved grape inhabitants, *tricincta* is to be found on wild stocks more often than either *comes* or *compta;* both these conditions agree with the productivity tests.

EFFECT OF TEMPERATURE

A change in temperature might conceivably affect the rate of oviposition in at least two rather distinct ways: (1) By direct effect upon the mechanism of egg deposition, and (2) by altering the rate of egg formation in the ovary. A correlation between the rate of egg laying and the temperature of the day the egg is laid might be attributed to either factor, but a correlation between rate and the temperature of the preceding day can be attributed only to the second factor. During the period covered by the oviposition records, June 18 to August 5, the daily mean temperatures, as recorded by the thermograph, varied from 17.4° to 29.2° C., and averaged 22.4°, with a standard deviation of 2.82°.

In Table 2 are given the original correlations of the zero order between laying rate and temperature. Of more importance, how-

ever, are the partial correlations of the third order, by which means spurious effects of the other measured factors may be eliminated. In this case $r_{1a.234}$ gives the net correlation between the laying rate (a) and the mean temperature of the day the eggs were laid (1) when the composite effect of the temperature of the preceding day (2), of the number of females per jar (3), and of the age of the females from the date of the first record (4) are eliminated. Similarly $r_{2a.134}$ is the partial correlation between laying rate (a) and temperature of the preceding day (2) when the other three factors (1), (3), and (4) are hypothetically made inoperative.

TABLE 2.—*Correlations between laying rate (a) of five forms of leaf hoppers and environmental factors of temperature (1 and 2), number of females per jar (3), and date (4); the first three species on Concord, the last two on Clinton grape*

Correlation coefficients	Species of leaf hopper				
	E. tricincta	E. comes	E. compta	E. vitifex	E. vitis
Original:					
r_{1a}	0.58	0.40	0.30	0.04	0.50
r_{2a}	.61	.48	.30	−.08	.55
r_{3a}	−.24	−.15	.23	.65	−.55
r_{4a}	.39	.12	−.13	−.66	.50
Partial:					
$r_{1a\cdot234}$	.41, [a].01	.13, .34	.17, .18	.16, .45	.20, .34
$r_{2a\cdot134}$	.42, [a].01	.30, .03	.26, .04	.03, .89	.29, .16
$r_{3a\cdot124}$	−.09, .54	−.18, .18	.20, .11	.17, .42	−.24, .24
$r_{4a\cdot123}$	.31, .04	.10, .47	−.32, .01	−.22, .29	−.06, .78
Multiple R	.67	.38	.49	.32	.43
Number of cases	48	60	68	27	28

[a] Value of P less than 0.01. As in Table 1, each partial coefficient is followed by its value of P.

It is at once apparent that the indirect effect of temperature upon rate of egg formation is generally of greater importance within the temperature range represented than its specific action as an "external" factor upon egg deposition. As is apparent from the correlations of laying rate with temperature of the two days, *comes*, *compta*, and *vitis* fall in one group, *tricincta* in another, and *vitifex* in a third. The greater dependence of *tricincta* upon temperature (twice as great) in comparison with *comes* may be correlated with its more restricted distribution geographically.

DENSITY OF POPULATION

Pearl (*5*) has demonstrated a marked decrease in progeny per female per day in Drosophila when the number of females to the bottle is increased, while Huettner (*2*) found that unless eggs were deposited regularly, eggs of Drosophila were laid at all stages of embryonic development. The number of female leaf hoppers per jar varied from 13 to 152, averaging from 54 (*tricincta*) to 76 (*vitis*). Under the conditions of the experiment, however, the effect of crowding this number on a single leaf or part of a leaf was barely appreciable. The partial correlation coefficients measuring this effect ($r_{3a.124}$) are of little significance; in the three commoner species the coefficients are negative, in the other two positive.

Approximate rates of egg laying for an equivalent calendar period were calculated from the experiments on fecundity reported by Johnson (*4*) and by Jewett (*3*). Using two, three, or four overwintering females per jar, Jewett found average rates of 1.2 for *comes*, 1.0 for *compta*, and 1.7 for *vitis* (species of grape not reported), rates of the same magnitude as those obtained here. With four single pairs in separate larger cages, Johnson obtained an average rate of about 2.3 for *comes*, for four pairs in a single cage an average of 1.9, and for nine pairs, also in a single cage, an average of 4.0. Certainly if there is an effect of density of population upon rate of laying under the experimental conditions so far employed, it is of very much smaller magnitude than in Drosophila populations.

SEASONAL CHANGES IN FERTILITY

Most, if not all, of the hoppers used were overwintering individuals, which laid eggs from June 18 to August 5, the mid-points of the records lying between July 10 and July 20 for the different species. Both Johnson and Jewett found a marked decrease in the number of offspring produced as the season progressed. In the present experiments, however, correlations of laying rate with the age of the females in days, numbered from the beginning of the experiments ($r_{4a.123}$), gave erratic results, varying from -0.32 (*compta*) to 0.31 (*tricincta*). That individual *tricincta* females actually laid more eggs as the season progressed is questioned, the significant positive correlation between laying rate and age in this species being attributed instead to a differential mortality. It is of interest, however, that the resultant effect of all factors involved in the seasonal change, as measured by the correlation coefficient, increases the productivity of *tricincta*, does not affect the oviposition of either *comes* or *vitis*, and decreases egg laying in the less abundant *compta* and *vitifex*.

THE TOTAL EFFECT OF ENVIRONMENT UPON LAYING RATE

The combined effect of all the environmental factors considered on reproductive rate upon a single species of host plant is given by the multiple correlation coefficient R, which may take any value from 0 to 1, and is given in Table 2. These vary from 0.32 (*vitifex*) to 0.67 (*tricincta*), and, except for *vitifex*, are all significantly different from 0. That no important environmental factor, common to all species, has been overlooked is indicated by three facts: (1) Correlations between laying rates on Concord and on Clinton on the same day are smaller than the multiple coefficients; (2) the correlation in laying rate between two lots of *compta* collected at the same time and place and covering 28 days of oviposition on Concord was 0.44 ($P=0.02$), in agreement with the multiple correlation coefficient 0.49; (3) the correlation of laying rate of *comes* with laying rate of *tricincta* on the same day was 0.33 ($P=0.03$), less than either multiple coefficient, these two species agreeing most closely in their partial coefficients.

In the best case, *tricincta*, the multiple correlation coefficient represents a control over laying rate of but 45 per cent. Accordingly, it would be futile to attempt to treat these data quantitatively. It is better to leave them in the qualitative form in which they have been presented.

SUMMARY

The productivity of grape leaf hoppers was investigated by means of the daily rate of oviposition by overwintering females. Of the five forms studied, *Erythroneura tricincta* var. *cymbium*, *E. comes* var. *comes*, and *E. comes* var. *compta* showed much greater productivity on *Vitis labrusca* stocks than on vines predominantly *V. vulpina*. *E. vitis* and *E. vitifex*, on the other hand, were more productive on *vulpina* stocks. Both of these conditions agree with the distribution of the respective species in the field.

The effect of different environmental conditions on laying rate was measured by partial-correlation methods. Of these environmental factors, temperature was found to condition oviposition more by its indirect effect upon egg development than by direct action on egg deposition. The effect of density of population was slight. The action of seasonal changes on rate of egg laying agreed with the relative abundance of the different species in the field. The total effect of the environment in these experiments, as measured by the multiple-correlation coefficient and other constants, was not large, but probably did not omit any important factor common to all the experiments.

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AN UNDESCRIBED WHITE FLY ATTACKING CITRUS IN PORTO RICO[1]

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As certain white flies are considered to be among the worst pests of citrus in various parts of the world, it is interesting to present here the following description of a new citrus-feeding species. Although at present not of economic importance in its native home in Porto Rico, it is of potential importance to other citrus-growing countries.

Paraleyrodes naranjae, new species

Very close to *Paraleyrodes goyabae*, a Brazilian species, but easily distinguished by the difference in male genitalia.

Egg.—Length 0.240 mm., width 0.112 mm. Pale yellow in color. Scattered over leaf and lying rather prostrate, attached at one extremity to long pale stalk.

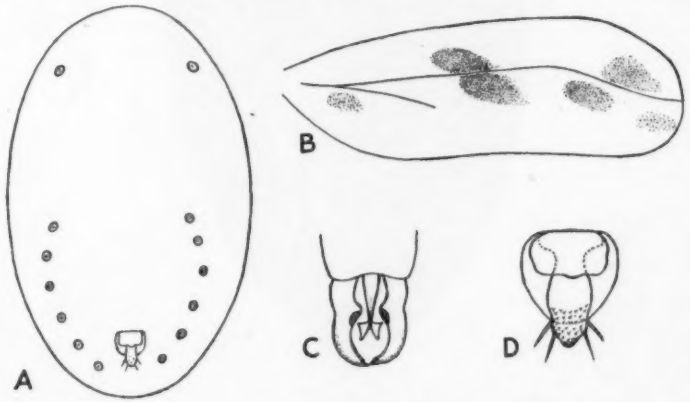

Fig. 1.—*Paraleyrodes naranjae;* A, pupa case; B, adult forewing; C, male genitalia; D, vasiform orifice

Second larval instar.—Distinctly orange-yellow, with a very short and fine fringe of waxy hairs around the margin.

Third instar.—The waxy fringe is much shorter than in the fourth instar and the thick wax filaments arising from the dorsal pores have not become so thick and high, although hiding the body even in this stage.

Fourth instar (pupa case).—Occurs scattered over the under surface of the leaf as small white waxy rosettes that measure about 1.50 mm. across. Case fringed with very broad white waxen filaments that curl downward, the case being completely hidden by the other very broad thick filaments that arise from

[1] Received for publication Feb. 24, 1927; issued June, 1927.

the dorsal pores and grow upward, curving slightly. Size of case about 0.85 by 0.50 mm.

ADULT MALE.—Body uniformly pale yellowish with the claspers a very distinct red in freshly mounted specimens. Length from head to tip of claspers 1.14 mm. Antennae very peculiar, three-jointed; the first joint cup-shaped, whitish, length 0.04 mm., second joint subpyriform, whitish, length 0.05 mm., third joint, golden yellow, extremely long, 0.55 mm., very much imbricated, a few hairs at tip. Eyes distinctly constricted, dark reddish-brown. Fore wing 0.95 mm. by 0.40

FIG. 2.—Sour-orange leaf infested with *Paraleyrodes naranjae*. Natural size

mm., with the radial sector and a short media retained, dusky spotted as in Figure 1; hind wings with single straight vein. Genitalia forcipate, the claspers 0.11 mm. in length, stout at base and curving.

ADULT FEMALE.—Smaller than the male, length to tip of ovipositor 0.81 mm. Body pale yellowish white. Antennae differ from those of male, being distinctly four-jointed.

Described from numerous adults, pupa cases, et cetera, collected by the writer on old sour-orange trees (fig. 2) in back-yard garden of Señor Hernandez Lopez at car stop 23, Santurce, Porto Rico, December 21, 1924, on which date they were abundant in association with the woolly white fly, *Aleurothrixus howardi* (Quaint.).

Paraleyrodes naranjae in all of its stages, including the egg, lies amid very short fine broken waxen rods scattered indiscriminately over the lower surface of the leaf.

A single female parasite, *Encarsia variegata* How. (determined by Gahan), was reared from this material January 3, 1925. However, the species was very heavily parasitized. Thirty out of a total of 49 pupa cases mounted on slides, or 61.2 per cent, showed evidences

FIG. 3.—Pupa of the parasite *Encarsia variegata*, lying in the pupa case of the white fly. Greatly enlarged

of parasitism. A single pupa of the parasite almost completely fills the pupa case of the host (fig. 3). *Encarsia variegata* was described by L. O. Howard [2] as a parasite of *Paraleyrodes perseae* in Florida.

[2] HOWARD, L. O. ON TWO NEW SPECIES OF PARASITES OF ALEYRODIDÆ. Ent. Soc. Wash. Proc. 10: 64. 1908.

THE YELLOW RUST OF RASPBERRY CAUSED BY PHRAGMIDIUM IMITANS[1]

By S. M. ZELLER

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INTRODUCTION

Although *Phragmidium imitans* Arthur is distributed from the Atlantic to the Pacific coast in the northern United States and southern Canada, it is not prevalent enough to be of economic interest except in the Pacific Northwest. Its geographical range is from Newfoundland and Massachusetts to Colorado and northern California, and northward into Canadian Provinces.

Phragmidium imitans occurs autoeciously on species of the genus Rubus, having been reported on *R. leucodermis* Douglas, *R. occidentalis* Linn., *R. spectabilis* Pursh, and *R. strigosus* Michx. The widest distribution is on the latter host, upon which it has been reported in Canada from Newfoundland and Nova Scotia to Ontario, and in British Columbia; and in the United States from Maine and Massachusetts to Montana and Colorado, and in Oregon and Washington. On the other species of Rubus, *P. imitans* is distributed as follows: On *R. leucodermis*, from northern California to British Columbia; on *R. occidentalis*, in Massachusetts, Newfoundland, Oregon, Washington, and British Columbia; and on *R. spectabilis*, in Oregon and Washington. The severest attacks are on *R. strigosus* and *R. spectabilis*.

TAXONOMY

The organism causing this disease was first described by Farlow[2] in 1879 as *Phragmidium incrassatum* Link *gracile* and later (1884) by Arthur[3] as *P. gracile*. Since the latter name was preoccupied (*P. gracile* Cook, 1871) and the fungus is similar to these other species, Arthur finally gave the name *P. imitans*.[4]

MORPHOLOGY

There is nothing strikingly distinctive in what is known of the morphology of *Phragmidium imitans*. It is very similar to the European species, *P. Rubi-Idaei* Karst. In *P. imitans* the pycnia, which are flattened lenticular bodies opening by irregular clefts through the overlying epidermis of the host, are typical of the genus. Under Oregon conditions they first appear on the upper surface of the leaves in April and early May. They are located at the centers of slightly elevated spots, occurring singly or more often in groups of two to four. These elevated spots are less than a millimeter in diameter,

[1] Received for publication Jan. 22, 1927; issued June, 1927. Published by permission of the Director of the Oregon Agricultural Experiment Station.

[2] ELLIS, J. B. NORTH AMERICAN FUNGI. Century III, no. 282. 1879.

[3] ARTHUR, J. C. PRELIMINARY LIST OF IOWA UREDINEAE. Iowa Agr. Col., Dept. Bot. Bul. 1884, p. 161. 1884.

[4] ARTHUR, J. C. AECIDIACEAE. North Amer. Flora 7: 165–166. 1912.

and may be slightly lighter in color than the normal tissues of the succulent raspberry leaves. If it were not for the tiny circular elevations upon which the pycnia occur, they would pass entirely unnoticed at this stage. When mature, pycnia are more conical than lens-shaped and measure 45μ to 90μ in diameter and 30μ to 35μ high.

The tiny elevations upon which the pycnia occur are the unruptured, developing aecia. These break through the epidermis and become noticeable from late in April and early May until late in July. They rupture the epidermis in small circular groups around the pycnia, becoming pulvinate. In color they are a light orange yellow, fading to pale yellow. They may occur scatteringly or so densely spotting the leaves (fig. 1, A) that early defoliation results. The circular aecia (fig. 1, B) are surrounded by incurved clavate paraphyses just inside of the fringing epidermis. The paraphyses are 10 to 15$\times$45 to 100μ, with thin, smooth, hyaline walls.

The aeciospores are globose to broadly ellipsoid, 16 to 24$\times$14 to 20μ in size, with pale-yellow, sparsely and sharply papillose walls.

The uredinia have been found as early as the first of May, but are generally most prevalent in badly infected plantings during the month of June. Nevertheless, they may be found more or less abundantly until the leaves are shed in the late fall. Uredinia occur in lesions on the underside of the leaves and on all types of stems, including the canes (fig. 1, C, D, and fig. 2, C),[5] fruiting laterals (fig. 2, A), and leaf petioles (fig. 2, B). On the leaves the uredinial lesions are roundish, but on stem tissues they are usually elliptical. They soon become so prolific in spore production that the separate uredinia are indistinguishable. The uredinia are circular, small, 0.1 to 0.2 mm. in diameter, the ruptured epidermis disappearing early; paraphyses encircling the sorus are rather numerous, incurved, somewhat clavate, 65 to 100$\times$11 to 17μ in size, with thin, colorless, smooth walls.

The urediniospores are broadly ellipsoid, 18 to 23$\times$15 to 18μ in size, orange to pale yellow, becoming almost white late in the season, with thin walls, sparsely and rather strongly verrucose-echinulate, and with obscure germ spores.

The telia come in the uredinial lesions, wherever they occur. They have been found from the middle of July until late into the winter. In late summer the telia, blackened by the teliospores, are conspicuous on the lower surface of the leaves (fig. 2, D) and on the cane lesions until spring (fig. 2, C).

The telia which range from 0.3 to 0.7 mm. in diameter, are scattered. They are blackish, and become naked early.

The teliospores are cylindrical 26 to 32$\times$80 to 127μ, in size usually rounded below; apex has a blunt, conical hyaline apiculus, 3μ to 13μ long which has from 6 to 10 cells (usually 8 or 9); wall very dark fuscous brown, closely and rather coarsely verrucose; pedicel rugose when dry, sometimes with a twisted appearance, 80μ to 120μ long, the upper portion colorless except near the spore, 9μ to 10μ in diameter, the lower portion colorless but the interior not clear, swelling in water to claviform, 14μ to 27μ in diameter.

[5] FRANK, A. A NEW PHASE OF THE RASPBERRY RUST. Wash. Agr. Expt. Sta. Mo. Bul. 4 (10): 15-16. 1917.

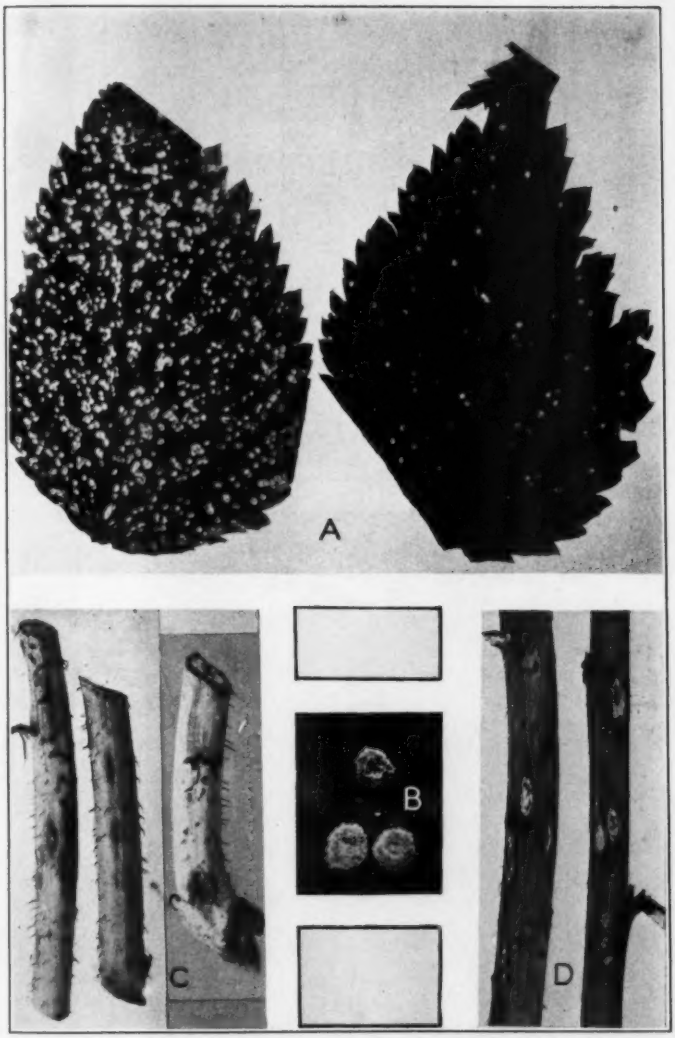

FIG. 1.—A, aecia on the upper surface of leaflets from the Cuthbert red raspberry Natural size. B, three aecial sori enlarged. ×10. C, uredinia on newly grown canes of the Cuthbert red raspberry, showing early stages of cane lesions beginning as dark water-soaked areas. Natural size. D, uredinial lesions on current year's canes late in the summer, showing an abundance of urediniospores. Natural size

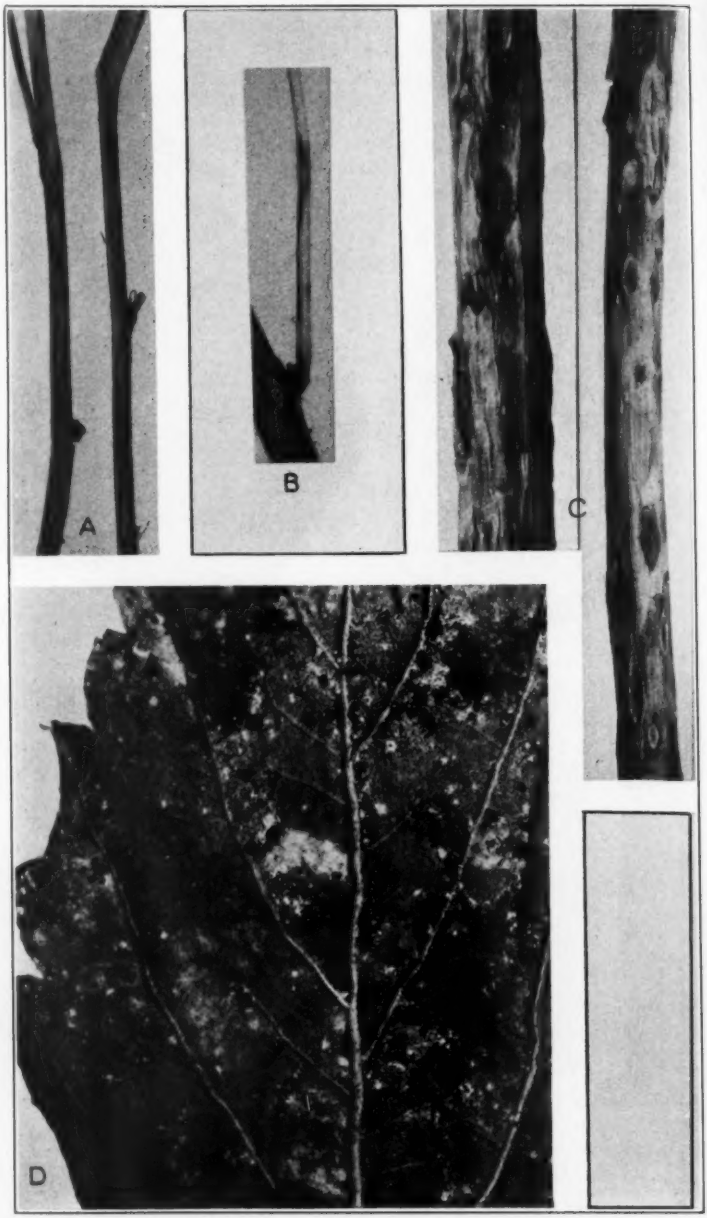

FIG. 2.—A, uredinial lesions on fruiting laterals of Cuthbert red raspberry taken in July. Natural size. B, a uredinial lesion on leaf petiole. Natural size. C, uredinial lesions with telia appearing subsequently in the same lesions near the base or ground line on two canes in their second season. Natural size. D, pale yellow uredinia and black telia on the lower surface of a Cuthbert leaf. ½ × 3

GERMINATION OF SPORES

No infection studies have been conducted, but several attempts have been made to germinate spores on microscope slides moistened with water. All attempts to germinate aeciospores have failed, but a very few teliospores have germinated and a considerable number of urediniospores. All attempts to germinate current season teliospores failed, but a very small percentage held over from the previous year have been induced to germinate in this way. Figure 3 shows a germinating teliospore of *Phragmidium imitans*, illustrating the type of promycelium produced and the subglobose sporidia which are hyaline and measure 4μ to 6μ in diameter. Figure 4 shows the germ tube of an urediniospore issuing from a terminal germ spore.

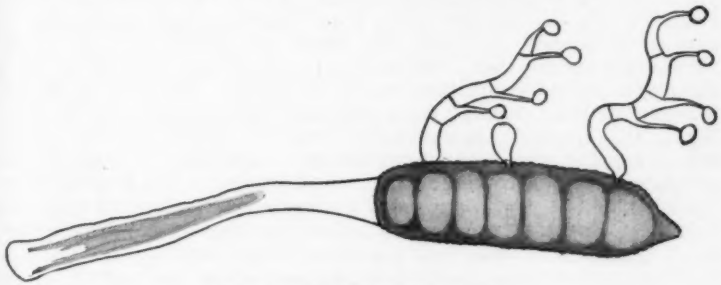

FIG. 3.—Germinating teliospore. ×500

ECONOMIC IMPORTANCE

The disease of the Cuthbert red raspberry caused by *Phragmidium imitans* develops to damaging proportions in the Pacific Northwest, particularly in seasons when the spring rains continue late. Under such conditions leaf infections become so numerous (fig. 1, A) that partial defoliation in badly infected plantings is frequently observed, and often more severe defoliation is reported. Berry pickers frequently have their clothing almost covered with the orange urediniospores. In seasons when leaf infections are so numerous as to produce any appreciable amount of defoliation the disease must have some devitalizing influence on the affected plants. However, the actual loss in crop during the current and subsequent years from this cause would be difficult to ascertain. The infection which causes uredinial lesions on the stems is the most serious and damaging phase of the disease.

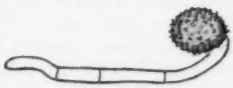

FIG. 4.—Germinating urediniospore. ×500

UREDINIAL LESIONS ON CANES

The greatest economic loss from raspberry rust is caused by the uredinial lesions on the stems. Frank [6] first called attention to these cane lesions in 1917, mentioning the fact that the spores produced in these lesions are doubtless an important factor in the carrying over of

[6] FRANK, A. Op. cit.

the fungus from one season to another. In answer to the writer's inquiry H. S. Jackson states that at the time the original description of *Phragmidium imitans* was made stem lesions were not known but that several years ago he found this disease on stems from western Washington. Although these uredinial lesions on the stems have been known for some years it is only recently that they have received detailed attention by the writer. In the summer of 1923 several growers of Cuthbert red raspberries in western Oregon called the writer's attention to the fact that they were sustaining a considerable loss of canes from some cause unknown to them. An investigation led to the conclusion that the loss was directly attributable to cane lesions.

During the summer when infection of the canes takes place the lesions on the green succulent canes do not present a serious aspect except where the lesions are so close together and so arranged as almost completely to girdle the stem. Comparatively few canes wilt or die during their first year. Losses from rust usually occur during the second or fruiting year of the canes. The infections near the ground have become deep and cankerous by the second year. (fig. 2, C). If they are numerous, they not only hinder the normal rise of sap but also produce brittleness in the canes. Many of the brittle canes are accidentally broken off when the old fruiting canes are trimmed out, and many more are broken out when the canes are trellised. Frequently, also, berries dry on the bushes before they reach maturity. Canes with numerous lesions near the base seldom have enough vascular tissues remaining to allow the passage of the amount of sap necessary to carry the fruit to maturity. In such cases the fruit of the whole cane suffers, while in the case of infections on the fruiting laterals the fruit of the individual lateral is damaged. (fig. 2, A). Leaves having petiolar infections (fig. 2, B) usually wilt and dry up during the heat of the summer, particulary if they are borne on the second-year fruiting canes and the fruit robs them of some moisture. Not infrequently the cane lesions produced by *Phragmidium imitans* are subsequently infected with *Fusarium viticola* Thüm, in which cases the pinkish sporodochia give to the lesions the appearance of anthracnose spots.

CONTROL

No satisfactory control measures have been found for this yellow raspberry rust. If in badly infected plantings the old fruiting canes are removed as soon after the harvest of the fruit as practical, much of the source of late summer infection will be removed. Where practical, all the fallen leaves and refuse resulting from the removal of the old canes should be raked up and burned. Early spring plowing to cover fallen leaves and refuse before the leaves come out offers the most practical method of control. Immediately after plowing, the refuse should be raked into the furrows before the first cultivation. If these sanitary measures are thoroughly carried out the disease should never become serious, although such measures do not eliminate the possibility of infection from lesions on the new canes. In most seasons, however, such infections are practically negligible.

A few tests have been made to determine the effectiveness of Bordeaux mixture spray, 3–3–50 in preventing infection of the newly

growing canes. One of these tests made in 1924 gave rather hopeful results. The tests made in 1925 and 1926, however, were unsatisfactory as the seasons were not favorable to rust and the unsprayed rows showed no lesions on the new canes. Three applications were given when the new canes were 4 to 12 inches, 16 to 20 inches, and 20 to 36 inches high, respectively. In the 1924 tests the sprayed canes were not infected in stems of leaves, but the unsprayed rows showed some cane lesions and moderate leaf infection. These results are merely indicative, since conditions in 1924 were not favorable for infection by *Phragmidium imitans*. Grove [7] says that in England the spread of *Phragmidium Rubi-Idaei* Karst. is prevented by sprays such as dilute Bordeaux mixture or potassium sulphide solution. A convincing test of Bordeaux spray as a preventive of *P. imitans* is impossible, however, in seasons as unfavorable to the disease as those of 1924, 1925, and 1926.

SUMMARY

In this paper is described the yellow rust of red raspberries caused by *Phragmidium imitans* Arthur. The geographic distribution of the rust and the species and varieties of Rubus upon which it occurs are briefly reviewed. The life history as observed on the Cuthbert red raspberry in the Northwestern Coast States is described, with particular reference to the uredinial lesions on the stems. The infection of second-year or fruiting canes near the ground is the most serious phase of the disease, since the resulting lesions produce brittleness and diminish sap-conducting tissues. Thus canes are easily broken in trellising, and the rise of sap may be insufficient for complete maturity of the fruit.

No satisfactory means of control are known, but extreme sanitary methods for the elimination of old leaf and cane refuse are the most practical methods suggested.

[7] GROVE, W. B. THE BRITISH RUST FUNGI (UREDINALES) THEIR BIOLOGY AND CLASSIFICATION. p. 299. Cambridge. 1913.

A COMPARISON OF THE DIRECT MEASUREMENT OF THE HEAT PRODUCTION OF CATTLE WITH THE COMPUTATION OF THE HEAT PRODUCTION BY THE RESPIRATORY-QUOTIENT METHOD [1]

By E. B. FORBES, *Director*, MAX KRISS, *Associate*, WINFRED W. BRAMAN, *Associate*, and R. B. FRENCH, *Assistant, Institute of Animal Nutrition, Pennsylvania State College* [2]

INTRODUCTION

The method of computation of the heat production of animals by the respiratory-quotient method—that is, from the carbon dioxide produced, the oxygen consumed, and the nitrogen of the urine—has seemed to require confirmation as applied to cattle, because of the modification of the standard procedure as employed with omnivora and carnivora which is necessitated by reason of the extensive fermentation of carbohydrates occurring in the alimentary tract of ruminants.

The present study was undertaken, therefore, to compare these computed values with direct measurements of the heat production by means of the respiration calorimeter of this institute—the only apparatus of the kind in existence of the size necessary for use with cattle. Obviously this comparison is of especial interest in relation to the heat-production values derived from the respiratory exchange as determined by means of the several respiration chambers which are being used in studies of the energy metabolism of cattle.

TABLE 1.—*Schedule of experiments*

Experiment No.	Animal	Period No.	Treatment
221E	Cow No. 885	3	Fasting; sixth day (*5*). [a]
221F	Cow No. 874	1	Supermaintenance (*4*).
221F	Cow No. 874	2	Maintenance (*4*).
221F	Cow No. 874	3	Fasting; ninth day (*5*).
221F	Cow No. 886	1	Supermaintenance; milk production (*4*).
221F	Cow No. 886	2	Do.
221F	Cow No. 887	1	Supermaintenance (*4*).
221F	Cow No. 887	2	Maintenance (*4*).
221F	Cow No. 887	3	Fasting; ninth day (*5*).
235	Steer No. 259	1a, 1b, 1c, 1d	Fasting; days 5 to 10½ (*5*).
235	Steer No. 259	2	Maintenance. [b]
235	Steer No. 259	3	Supermaintenance. [b]
235	Steer No. 260	1a, 1b, 1c, 1d	Fasting; days 4 to 9½ (*5*).
235	Steer No. 260	2	Maintenance. [a b]
235	Steer No. 260	3	Supermaintenance. [a b]

[a] Reference is made by number (italic) to "Literature cited," p. 878. [b] Unpublished data.

Accordingly, quantitative determinations were made, in connection with three comparatively recent experiments, of the oxygen of the air coming from the respiration calorimeter chamber; the other data

[1] Received for publication Mar. 2, 1927; issued June, 1927.

[2] The inception of this study was due to H. P. Armsby, who planned the first two of the three experiments involved. Those who have contributed most extensively to the organization of the results are Max Kriss, D. C. Cochrane, and R. B. French. The performance of the experiments and the dependent analytical work and computations are credited especially to J. A. Fries, W. W. Braman, Max Kriss, D. C. Cochrane, C. D. Jeffries, R. W. Swift, R. B. French, J. V. Maucher, and R. M. Meredith.

used in the computation of the heat production by the respiratory-quotient method being regularly determined in providing for the confirmation of the direct-heat measurements by comparison with the heat production as computed from the balance of matter and energy.

The schedule of experiments discussed, including references to publications of the full accounts, comprises Table 1.

DISCUSSION OF METHODS OF EXPERIMENTATION AND OF DATA INVOLVED IN COMPUTATIONS

The direct measurements of the heat production which are involved in this comparison were made by the standard method followed at this institution from the time of inception of its program of research in animal calorimetry in 1902 to the present date. The main portion of the heat given off by the animal is directly measured in a stream of cooling water which flows through copper piping in the respiration chamber, the only other large portion of the heat produced being that used to vaporize the moisture given off from the animal's skin and lungs. The equipment provides for the direct weighing of this moisture, thus permitting the computation of the corresponding latent heat of water vapor.

In the indirect respiratory-quotient method of computation of the heat production the following data are involved: the carbon dioxide and oxygen of the ingoing and the outcoming air, the cumbustible gases (methane) of the outcoming air, and the nitrogen of the urine. Two procedures for dealing with the gases and heat of fermentation are compared, that of Andersen (*1*), and another in which the factors expressing the relation of the heat of fermentation to the methane produced, and the relation of the CO_2 to CH_4 of fermentation, were as recommended by Krogh and Schmit-Jensen (*7*). For the sake of brevity the second procedure is referred to as that of Krogh.

Since the composition of the air coming from the calorimeter varies much throughout the day, in accord with variations in the voluntary and the vital activities of the animal and with lapse of time since feeding, it is obvious that no system of intermittent sampling of the air can be depended upon accurately to represent the entire volume involved. Provision should be made, therefore, for the collection and analysis of a continuous aliquot of the air, the rates of ventilation and of sampling being maintained constant, or the rate of sampling being so controlled as to be accurately responsive to uncontrolled variations in the rate of ventilation.

In these experiments determinations of CO_2 were made in continuous aliquots of the air, as above specified, and also in intermittent samples taken at half-hour intervals; but oxygen was determined only in samples taken at half-hour intervals. The comparison to be made, therefore, between the direct and the respiratory-quotient methods of measurement of heat production should be considered in relation to the details of the particular procedures followed, which, in relation to the respiratory-quotient method, fail obviously to provide for the greatest accuracy of measurement practicably obtainable, even though the procedure followed probably compares favorably as to accuracy with the methods of most of the workers who utilize the respiratory-quotient method.

Whatever the facts as to the accuracy of the work by the respiratory-quotient method, and whatever the procedure—direct or indirect—which is followed, it is the feeling of the writers that it is of importance in studies of the utilization of feed energy by cattle that the utmost practicable nicety of procedure be employed.

Accordingly, in the light of the results of the preliminary studies here reported, this institute has undertaken to develop simple and accurate meter pumps, and accurately synchronous aliquoting spirometers for use with large farm animals and others for use with small laboratory subjects such as rats.

It is well known that the composition of the outside air is characterized, in general, by a high degree of constancy. It was not considered necessary, therefore, in the experiments here discussed to take as many samples of the ingoing as of the outcoming air. In the experiments with steers three samples of the outside air were taken during each 12 hours, and the average analysis for CO_2 and O_2 was used. In the earlier experiments with the cows only one or two such samples were taken during each 12 hours; and in a few cases the value used for carbon dioxide was that which was determined gravimetrically in a continous sample taken for use in determining the carbon balance, oxygen being determined gasometrically, as usual, but in continuous samples collected over water in an aspirator.

For the purposes of this comparison, in the experiments with cows the samples of the outcoming air were taken at half-hour intervals, exactly on the hour and half hour, during the last two consecutive 12-hour subperiods of a 48-hour calorimeter experiment.

In the experiments with steers the samples of the outcoming air were taken during every other subperiod, that is, during 12 hours of each experimental day. The samples were taken on the hour and the half hour except when the animal changed position shortly before the regular time for sampling, in which case an interval of at least 10 minutes was allowed to elapse before samples were taken.

Tables 2, 3, and 4 are presented as samples of the foundation data from which the heat production was computed, on planes of fasting, maintenance, and supermaintenance (production), respectively.

A study of these tables shows that the main influences which affected the composition of the outcoming air were the position of the animal, as to standing and lying, the plane of nutrition, and the time elasped since feeding. Also, since it would take from 25 to 40 minutes, according to the prevailing rate of ventilation, to pump through the calorimeter an amount of air equal to the capacity of the chamber, it is obvious that there was a very considerable lag—much more than 25 to 40 minutes—in the effect of the three above-mentioned influences on the composition of the outcoming air.

The effect of the position of the animal, as to standing and lying, is a complicated one, since it covers not only the characteristic rate of metabolism *in* the position, but also the exertion of *taking* the position; and the resultant from the combination of the approximately constant value for maintenance in a position with the diminishing effect of the effort of taking the position may hold over, on account of the instrumental lag, from an interval of time spent in one position through one or more subsequent intervals and positions.

TABLE 2.—*Percentage of carbon dioxide and oxygen in the outcoming air; experiment 235; periods 1a and 1b; steer 259; fasting*

Period 1a; subperiod 1				Period 1b; subperiod 1			
Time of sampling	Position of animal	Carbon dioxide, by volume	Oxygen, by volume	Time of sampling	Position of animal	Carbon dioxide, by volume	Oxygen, by volume
		Per cent	*Per cent*			*Per cent*	*Per cent*
P. m. 6. 10	Standing	0. 349	20. 510	A. m. 6. 00	Lying	0. 266	20. 632
6. 30	do	. 383	20. 486	6. 30	do	. 248	20. 661
7. 15	do	. 360	20. 504	7. 00	do	. 228	20. 669
7. 30	do	. 355	20. 519	8. 00	Standing	. 279	20. 603
8. 00	do	. 352	20. 505	8. 30	do	. 302	20. 577
8. 30	do	. 335	20. 527	9. 00	Lying	. 278	20. 601
9. 00	do	. 332	20. 545	9. 30	do	. 251	20. 647
9. 30	do	. 338	20. 528	10. 35	Standing	. 292	20. 593
10. 00	do	. 321	20. 549	11. 00	do	. 319	20. 555
10. 30	do	. 337	20. 531	11. 37	Lying	. 332	20. 552
11. 10	Lying	. 320	20. 553	Noon 12. 00	do	. 286	20. 597
11. 30	do	. 314	20. 580	P. m. 12. 30	do	. 256	20. 640
Midnight 12. 00	Standing	. 338	20. 535	1. 00	do	. 248	20. 646
A. m. 12. 32	Lying	. 358	20. 525	1. 30	do	. 263	20. 633
1. 00	do	. 309	20. 575	2. 00	Standing	. 336	20. 545
1. 30	do	. 297	20. 589	2. 30	do	. 350	20. 516
2. 00	do	. 269	20. 620	3. 00	do	. 344	20. 532
2. 30	do	. 262	20. 631	3. 30	Lying	. 305	20. 567
3. 00	do	. 267	20. 623	4. 00	do	. 277	20. 610
3. 40	Standing	. 305	20. 578	4. 30	do	. 272	20. 612
4. 10	Lying	. 313	20. 574	5. 00	Standing	. 357	20. 470
4. 30	do	. 275	20. 619	5. 30	do	. 417	20. 473
5. 30	do	. 260	20. 650				
6. 00	do	. 257	20. 632				

TABLE 3.—*Percentage of carbon dioxide and oxygen in the outcoming air; experiment 221F; cow 887; period 2; maintenance*

Subperiod 3				Subperiod 4			
Time of sampling	Position of animal	Carbon dioxide, by volume	Oxygen, by volume	Time of sampling	Position of animal	Carbon dioxide, by volume	Oxygen, by volume
		Per cent	*Per cent*			*Per cent*	*Per cent*
P. m. 6. 00				A. m. 6. 00	Standing	0. 236	20. 673
6. 30	Standing	0. 354	20. 612	6. 30	do	. 317	20. 601
7. 00	do	. 375	20. 615	7. 00	do	. 357	20. 578
7. 30	do	. 352	20. 628	7. 30	do	. 321	20. 618
8. 00	do	. 334	20. 631	8. 00	do	. 318	20. 634
8. 30	do	. 318	20. 627	8. 30	do	. 322	20. 590
9. 00	do	. 315	20. 635	9. 00	do	. 314	20. 598
9. 30	Lying	. 289	20. 650	9. 30	do	. 288	20. 616
10. 00	do	. 276	20. 671	10. 00	do	. 295	20. 548
10. 30	do	. 249	20. 683	10. 30	do	. 284	20. 651
11. 00	do	. 243	20. 687	11. 00	do	. 286	20. 620
11. 30	do	. 248	20. 703	11. 30	Lying	. 272	20. 638
Midnight 12. 00	do	. 238	20. 712	Noon 12. 00	do	. 252	20. 685
A. m. 12. 30	do	. 231	20. 686	P. m. 12. 30	do	. 250	20. 684
1. 00	do	. 258	20. 671	1. 00	do	. 224	20. 697
1. 30	do	. 254	20. 659	1. 30	do	. 232	20. 688
2. 00	Standing	. 260	20. 630	2. 00	do	. 233	20. 698
2. 30	do	. 260	20. 638	2. 30	do	. 234	20. 668
3. 00	do	. 256	20. 640	3. 00	do	. 247	20. 681
3. 30	Lying	. 268	20. 652				
4. 00	do	. 240	20. 666				
4. 30	Standing	. 232	20. 678	4. 30	Standing	. 238	20. 681
5. 00	do	. 245	20. 656	5. 00	do	. 241	20. 686
5. 30	do	. 245	20. 654	5. 30	do	. 246	20. 681
6. 00	do	. 236	20. 673	6. 00	do	. 244	20. 675

TABLE 4.—*Percentage of carbon dioxide and oxygen in the outcoming air; experiment 221F; cow 874; period 1; supermaintenance*

Time of sampling		Subperiod 3			Time of sampling		Subperiod 4		
		Position of animal	Carbon dioxide, by volume	Oxygen, by volume			Position of animal	Carbon dioxide by volume	Oxygen, by volume
			Per cent	*Per cent*				*Per cent*	*Per cent*
P. m.	6.00				A. m.	6.00	Standing	0.331	20.618
	6.30	Standing	0.463	20.518		6.30	do	.442	20.536
	7.00	Lying	.506	20.544		7.00	do	.490	20.589
	7.30	do	.464	20.587		7.30	do	.462	20.543
	8.00	Standing	.431	20.589		8.00	Lying	.463	20.513
	8.30	Lying	.438	20.551		8.30	do	.402	20.580
	9.00	do	.390	20.610		9.00	do	.375	20.601
	9.30	do	.358	20.630		9.30	Standing	.413	20.554
	10.00	Standing	.386	20.578		10.00	Lying	.426	20.551
	10.30	Lying	.406	20.558		10.30	do	.379	20.576
	11.00	do	.357	20.605		11.00	do	.353	20.613
	11.30	do	.335	20.620		11.30	Standing	.401	20.556
Midnight	12.00	Standing	.374	20.580	Noon	12.00	do	.398	20.559
A. m.	12.30	Lying	.363	20.592	P. m.	12.30	Lying	.392	20.569
	1.00	do	.342	20.631		1.00	do	.335	20.619
	1.30	Standing	.367	20.596		1.30	do	.327	20.627
	2.00	Lying	.376	20.605		2.00	Standing	.375	20.579
	2.30	do	.318	20.647		2.30	Lying	.346	20.607
	3.00	do	.310	20.653		3.00	do	.325	20.636
	3.30	Standing	.329	20.623		3.30	do	.316	20.639
	4.00	Lying	.330	20.629		4.00	Standing	.350	20.603
	4.30	do	.313	20.656		4.30	do	.344	20.609
	5.00	Standing	.349	20.626		5.00	do	.357	20.588
	5.30	do	.335	20.633		5.30	do	.341	20.603
	6.00	do	.331	20.618		6.00	do	.334	20.598

We may conceive of the plane of nutrition as affecting the composition of the outcoming air in a rather definite manner, in view of the fact that the feed intake is normally constant throughout a metabolism experiment.

The effect of the time elapsed since feeding varies in another characteristic manner, rising and falling in a periodic variation coincident with the 12-hour interval between times of feeding.

In the feeding periods (Tables 3 and 4) there was invariably an increased percentage of carbon dioxide and a decreased percentage of oxygen in the air samples taken during the first hour or two after feeding (at 6 o'clock, morning and evening); and the fall in percentage of oxygen was generally less prominent than the rise in the percentage of carbon dioxide. This suggests that the increased outgo of carbon dioxide after feeding is not wholly due to muscular exertion, but is partly caused by increased emission of products of fermentation of the food, a process in which the oxygen involved may be at least in part, if not wholly, of intramolecular rather than atmospheric origin.

In the light of these observations it is obvious that the composition of the outcoming air, at any particular time, must be the resultant of such a complication of influences that no short-time period of observation can with propriety be assumed accurately to represent the whole day; and this situation would not be rendered satisfactory by taking samples of air only while the animal is in a standard position (either standing or lying), since this could, at best, obviate only one of a great complication of contributing influences.

The validity of this observation has been rendered especially clear through an effort of one of the writers to compute, from data such

as comprise Table 2 (fasting), an average or standard difference in heat production during standing and lying. So prominent were the effects on the outgo of CO_2, of the influences cited above, other than those related to the feed, that it was found, even with these factors eliminated, to be quite impossible, unless the animal remained in one position for an unusually long time, to obtain evidence of value on this factor; and since the half-hour air samples were found to be very often invalid for this purpose it is obvious that an average of analyses of a few half-hour samples can not be considered an entirely accurate basis for the computation of a respiratory quotient.

In computing the heat production of cattle by the respiratory-quotient method it is necessary to modify the usual procedure on account of the extensive fermentation which takes place in the ruminant alimentary tract.

Two methods of recognition of this fermentation factor have been proposed, one by A. C. Andersen (*1*) and one by Krogh and Schmit-Jensen (*7*).

In Andersen's method the computation of the nonprotein respiratory quotient is based on values for carbon dioxide produced and for oxygen consumed covering not only the metabolism of the animal but also the fermentation in the alimentary tract, and the complete oxidation of the methane produced. From the heat production as computed by the use of the respiratory quotient thus determined is subtracted the energy value of the methane itself; thus the heat of fermentation, the amount of which is unknown, is included, and the energy represented by the methane is excluded.

The following example of the use of this method is based on results of experiment 221F, cow 886, period 1.

Experiment with a milking cow:

CO_2 produced = 2,670 liters.
O_2 consumed = 2,568 liters.
CH_4 produced = 254 liters.
CO_2 produced if CH_4 is oxidized = 254 liters.
O_2 used if CH_4 is oxidized = 508 liters.
Energy of CH_4 = 2,438 Calories.
Nitrogen in urine = 95.6 gm.
CO_2 produced in protein metabolism = $95.6 \times 4.75 = 454$ liters.
O_2 consumed in protein metabolism = $95.6 \times 5.94 = 568$ liters.
Energy of protein = $95.6 \times 26.51 = 2{,}534$ Calories.
CO_2 produced from nonprotein substances = $2{,}670 + 254 - 454 = 2{,}470$ liters.
O_2 consumed by nonprotein substances = $2{,}568 + 508 - 568 = 2{,}508$ liters.

Nonprotein R. Q. $= \frac{2{,}470}{2{,}508} = 0.985$.

Energy of nonprotein substances = $2{,}508 \times [4.686 + 1.23(0.985 - 0.707)] = 12{,}610$ Calories.

Total heat production = 12,610 Calories + 2,534 Calories for protein − 2,438 Calories in CH_4 = 12,706 Calories.

Constants employed:

Respiratory quotient for fat = 0.707 = 4,686 Calories per liter CO_2.
Respiratory quotient for carbohydrates = 1.00 = 5.047 Calories per liter CO_2.

From these values, for every 0.001 increase in respiratory quotient above 0.707 the heat per liter O_2 increases, above 4.686 Calories, by 0.00123 Calories.

Oxygen consumed per gram urinary N = 5.94 liters.
Calorific value per gram urinary N = 26.51 Calories.
Calorific value per liter O_2 consumed in protein metabolism = 4.463 Calories.
CO_2 produced per liter of O_2 consumed in protein metabolism = 0.801 liters.
CO_2 produced per gram of urinary nitrogen = 4.75 liters.

For places of publication and discussion of these factors see references (*1*, *6*, *8*, *9*, *11*, *12*);[3] and for computing the heat production when the respiratory quotient exceeds 1.0 see references (*10*, *13*, *14*).

The special purpose of Andersen's (*1*) method may be considered to be to account for the heat of fermentation, which it does, along with all other factors of heat production. In effect, this method assumes that in the fermentation of carbohydrates in the alimentary tract either methane is the only incompletely oxidized product or, if there are other incompletely oxidized products of fermentation, their oxidation is completed after absorption from the alimentary tract, so that in any case after accounting for the incomplete oxidation of methane the relation between oxygen, carbon dioxide, and heat is the same as that prevailing in complete oxidation of carbohydrates.

Krogh's (*7*) method assumes that no atmospheric oxygen is consumed in the fermentation of carbohydrates in the alimentary tract; that is, that this process is strictly anaerobic, and, therefore, for the derivation of the nonprotein respiratory quotient an estimated amount of CO_2 due to fermentation is subtracted from the total CO_2 representing the metabolism of nonprotein substances, but no correction is made in the corresponding value for oxygen required. The CO_2 of fermentation is estimated from the methane production by the use of the factor 2.6, i. e., liters of methane $\times 2.6$ = liters of CO_2. To the heat production as computed from this respiratory quotient and oxygen consumption is added the heat of fermentation, estimated to be 50 Calories per gram molecule of CH_4, or 2.25 Calories per liter of methane.

The application of this method is illustrated by Krogh and Schmit-Jensen (*7*) as follows:

The metabolism of nitrogen-free substances was found to require 1,451 liters of oxygen, and produced 1,583 liters CO_2 and 127 liters CH_4. The CO_2 of fermentation would be $2.6 \times 127 = 330$ liters, and the true respiratory quotient for the organism itself would be $\frac{1583-330}{1451} = 0.864$.

The energy metabolism is calculated from the oxygen intake by means of Zuntz's (*15*) formulas $E = O_2[4.686 + (R.\,Q. - 0.707)1.23]$.

In this case $E = 1{,}451[4.686 + (0.157 \times 1.23)] = 7{,}079$ Calories.

To obtain the total heat production it is necessary to add to 7,079 Calories the heat of fermentation, which, in this case, would be $127 \times 2.25 = 286$ Calories, and also the energy equivalent of the protein metabolized.

[3] Certain constants which the writers have employed—5.94 for liters of oxygen per gram of urinary nitrogen and 4.463 for Calories per liter of oxygen consumed in protein metabolism—differ slightly from those used by some investigators. These differences are due to an arithmetical error in the publication of Loewy (*9*, *p. 279*), which was discovered by one of the writers, and to which it is here desired to call attention. In that publication the figure 5.91 is given instead of 5.94 as the result of the division 96.63÷16.28; and dividing 26.51 by 5.94 gives 4.463 instead of 4.485, as in Loewy's paper.

TABLE 5.—*Average composition of ingoing and outcoming air [a] and total ventilation; experiments 221E, 221F, and 235; animals fasting*

Experiment No.	Animal	Period No.	Subperiod No.	Ingoing air			Outcoming air				Total ventilation	
				Carbon dioxide	Oxygen	Nitrogen	Carbon dioxide	Oxygen	Methane	Nitrogen	Ingoing	Outcoming
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Liters*	*Liters*
221E	Cow 885	3	3	0.031	20.909	79.060	0.172	20.718	0.001	79.109	355,208	354,988
			4	.033	20.895	79.072	.178	20.701	.001	79.120	347,408	347,197
221F	Cow 874	3	3	.033	20.919	79.048	.179	20.730	.001	79.090	360,164	359,973
			4	.033	20.914	79.053	.180	20.715	.001	79.104	353,657	353,429
	Cow 887	3	3	[b].331	20.915	79.054	.162	20.743	.000	79.095	361,918	361,731
			4	[b].032	[c]20.915	79.053	.163	20.738	.000	79.099	360,442	360,232
235	Steer 259	1a	1	.039	20.925	79.036	.317	20.562	.002	79.119	234,409	234,163
		1b	1	.033	20.932	79.035	.295	20.588	.001	79.116	234,554	234,314
		1c	1	.038	20.922	79.040	.280	20.609	.001	79.110	231,151	230,947
		1d	1	.033	20.934	79.033	.267	20.626	.001	79.106	226,695	226,485
	Steer 260	1a	1	.032	20.929	79.039	.252	20.646	.001	79.101	232,473	232,291
		1b	1	.033	20.916	79.051	.235	20.660	.001	79.104	233,146	232,989
		1c	1	.033	20.929	79.038	.245	20.652	.000	79.103	227,547	227,360
		1d	1	.032	20.934	79.033	.228	20.679	.000	79.093	234,876	234,698

[a] All percentages are by volume, and all data in this table are on the dry basis.
[b] Gravimetric determination.
[c] Outside air sample lost; O_2 assumed to be the same as in subperiod 3.

TABLE 6.—*Average composition of ingoing and outcoming air [a] and total ventilation; experiment 221F; animals on feed*

Animal	Period No.	Subperiod No.	Ingoing air			Outcoming air				Total ventilation	
			Carbon dioxide	Oxygen	Nitrogen	Carbon dioxide	Oxygen	Methane	Nitrogen	Ingoing air	Outcoming air
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Liters*	*Liters*
Cow 874	1	3 (night)	0.033	20.919	79.048	0.374	20.603	0.030	78.993	361,516	361,768
		4 (day)	[b].032	20.910	79.058	.379	20.587	.030	79.004	358,576	358,821
	2	3 (night)	[b].032	20.920	79.048	.281	20.675	.023	79.021	359,422	359,545
		4 (day)	.031	20.923	79.046	.284	20.669	.023	79.024	353,746	353,844
Cow 887	1	3 (night)	.033	20.907	79.060	.339	20.615	.029	79.017	351,775	351,966
		4 (day)	.031	[c]20.901	79.068	.370	20.578	.031	79.021	344,843	345,048
	2	3 (night)	[b].033	20.880	79.087	.274	20.657	.021	79.048	360,927	361,105
		4 (day)	.032	20.898	79.070	.272	20.647	.020	79.061	361,083	361,124
Cow 886	1	3 (night)	.030	20.923	79.047	.413	20.541	.036	79.010	347,123	347,286
		4 (day)	[b].031	20.917	79.052	.418	20.537	.037	79.008	346,114	346,307
	2	3 (night)	.030	20.905	79.065	.413	20.553	.038	78.996	354,659	354,969
		4 (day)	.031	[c]20.901	79.068	.426	20.535	.038	79.001	353,921	354,221
Steer 259	2	1 (day)	.033	20.928	79.039	.308	20.641	.019	79.032	318,692	318,720
		3 (day)	.032	20.930	79.038	.312	20.642	.020	79.026	318,163	318,211
		5 (day)	.033	20.930	79.037	.301	20.661	.020	79.018	323,070	323,148
	3	1 (day)	.035	20.916	79.049	.407	20.556	.030	79.007	321,308	321,479
		3 (day)	.037	20.914	79.049	.402	20.555	.030	79.013	319,540	319,686
		5 (day)	.032	20.916	79.052	.412	20.543	.030	79.015	320,168	320,318
Steer 260	2	1 (day)	.036	20.912	79.052	.300	20.657	.018	79.025	317,547	317,655
		3 (day)	.036	20.919	79.045	.299	20.651	.019	79.031	317,889	317,946
		5 (day)	.033	20.919	79.048	.301	20.650	.019	79.030	314,554	314,625
	3	1 (day)	.033	20.922	79.045	.387	20.580	.027	79.006	320,768	320,926
		3 (day)	.031	20.924	79.045	.390	20.576	.027	79.007	319,721	319,874
		5 (day)	.034	20.927	79.039	.386	20.580	.029	79.005	316,981	317,117

[a] All percentages are by volume and all data in this table are on the dry basis.
[b] Gravimetric determination.
[c] Determined in aspirator sample.

Tables 5 and 6 give the average analyses of the air, both ingoing and outcoming, and the total ventilation per subperiod of 12 hours.

We have no basis for judging the significance of the differences in the composition of the ingoing air; the composition is simply reported as determined.

In Table 5 the higher percentages of carbon dioxide and the lower percentages of oxygen, in the experiments with the steers, are due to the slower rate of ventilation which prevailed—this slower rate being as shown in the two columns giving the total incoming and outgoing air.

The very small amount of methane found in the outcoming air—a maximum of two parts per 100,000 in one subperiod with steer No. 259—shows that the animals were in an essentially true state of fast. Had there been feed residues in the alimentary tract, in any significant quantities, there would probably have been more considerable evidence of fermentation.

All figures for methane were computed to volume per cent, as reported, from continuous 12-hour gravimetric determinations.

The differences in analyses of the air in consecutive subperiods are to a considerable extent the consequences of variations in the electric power, as affecting the rate of ventilation.

A comparison of the analyses of the outcoming air in Table 5 with those in Table 6 shows the influence of feed on the respiratory exchange. Under the influence of feed more carbon dioxide and methane were produced, and more oxygen was used, than during fast.

From the differences in composition of the ingoing and the outcoming air, as exhibited in these tables, and the nitrogen of the urine, the respiratory quotients and the heat production were computed.

Both Andersen's (*1*) and Krogh's (*7*) methods require the same accounting for the protein metabolism, the basis for so doing being satisfactory in the experiments with steers on feed, since in these the urine was collected separate from the feces, and was composited during 18 days; while with the cows which received feed the conditions were less satisfactory, since with these the feces and urine were collected together, during only 10 days, and it was necessary to estimate the urinary nitrogen indirectly from the amount associated with the crude fiber as determined in the feces-and-urine mixture.

The estimation of the protein metabolism of the fasting steers was definitely unsatisfactory, in view of the irregularity of excretion of urine, and the fact that the excretion for only the last four days of fast could be used.

The estimation of the protein katabolism of the fasting cows was still less satisfactory since they were not catheterized, and since the amounts of urine and feces were based on a mechanical separation of these excreta for the two calorimeter days, after having been collected together.

DISCUSSION OF RESULTS

The respiratory quotients and dependent computations of the heat production are given for fasting cows and steers in Table 7, and for such animals on feed in Tables 8 and 9.

The nonprotein respiratory quotients for fasting steers (Table 7) were slightly above 0.7; thus, they were normal.

With the fasting cows the nonprotein respiratory quotients were appreciably below normal in four cases among six.

These low quotients might conceivably result from incomplete oxidation of fat, from synthesis of carbohydrate from fat or protein, or from inaccuracies in sampling or analytical work.

TABLE 7.—*Respiratory quotients and heat production of fasting animals*

Experiment, animal, period, and subperiod No.	Total CO_2 produced		Total O_2 consumed, intermittent sample	Respiratory quotients		Total heat production				
						Computed		Observed	Computed / Observed	
	Intermittent sample	Continuous sample		Total	Nonprotein	Intermittent CO_2	Continuous CO_2		Intermittent CO_2	Continuous CO_2
	Liters	*Liters*	*Liters*			*Calories*	*Calories*	*Calories*	*Per cent*	*Per cent*
Experiment 221E:										
Cow 885—										
Period 3 {3 (night)	500.5	517.7	724.0	0.691	0.663	3,360.5	3,483.3			
Period 3 {4 (day)	503.4	510.7	717.6	.702	.676	3,330.9	3,382.0			
Per day						6,691.4	6,865.3	6,575.6	101.8	104.4
Experiment 221F:										
Cow 874—										
Period 3 {3 (night)	525.5	527.4	720.3	.730	.713	3,347.4	3,361.5			
Period 3 {4 (day)	519.5	519.1	751.0	.692	.670	3,491.5	3,486.8			
Per day						6,838.9	6,848.3	6,657.7	102.7	102.9
Cow 887—										
Period 3 {3 (night)	473.8	482.7	661.4	.716	.703	3,079.8	3,137.4			
Period 3 {4 (day)	471.9	479.8	681.4	.693	.676	3,173.7	3,227.6			
Per day						6,253.5	6,365.0	6,227.9	100.4	102.2
Experiment 235:										
Steer 259—										
Period 1, subperiod 1 (night)	650.9	641.7	901.5	.722	.710	4,199.9	4,141.7	4,292.5	97.8	96.5
Period 2, subperiod 1 (day)	613.8	612.1	856.3	.717	.706	3,991.3	3,978.2	3,837.4	104.0	103.7
Period 3, subperiod 1 (night)	558.9	555.3	765.7	.730	.719	3,577.0	3,540.8	3,780.8	94.6	93.7
Period 4, subperiod 1 (day)	529.9	533.5	741.4	.715	.702	3,453.2	3,475.7	3,392.9	101.8	102.4
Steer 260—										
Period 1, subperiod 1 (night)	511.0	492.8	695.5	.735	.726	3,259.2	3,141.5	3,288.5	99.1	95.5
Period 2, subperiod 1 (day)	470.6	463.6	629.1	.748	.741	2,957.2	2,912.8	3,043.7	97.2	95.7
Period 3, subperiod 1 (night)	484.2	470.2	673.4	.718	.710	3,143.6	3,051.2	3,230.0	97.4	94.5
Period 4, subperiod 1 (day)	459.9	463.4	638.2	.721	.711	2,979.3	3,002.8	3,037.2	98.1	98.9

As bearing on this point, Carpenter (*2*) has shown that there is no appreciable fasting ketosis in cattle.

Also, in experiment 221F, with both cows 874, period 3, and 887, period 3, the respiratory quotients in one of the two consecutive subperiods is above 0.7, and in the other considerably below 0.7; further, in the cow experiments the pyrogallate solution used in the oxygen estimation was changed less frequently than in the steer experiments, and this may have resulted in low oxygen values in the outcoming air, high values for oxygen consumption, and low respiratory quotients. The probability, therefore, seems to be that these subnormal nonprotein respiratory quotients are due to imperfect technic.

In Table 8 are set forth the nonprotein respiratory quotients of the animals while on feed, these quotients being based on the volumetric analysis of the half-hour air samples, and being computed by the methods of Krogh (*7*) and of Andersen (*1*).

The quotients computed by the method of Andersen are all appreciably higher than those computed by the method of Krogh. The former are all close to 1.0, above or below, while the latter are in

general from one to two tenths less. In view of the fundamental difference in the procedures, which has been explained, the quotients computed by the two methods have a somewhat different significance, and therefore are not logically comparable as on the same basis.

TABLE 8.—*Respiratory quotients and heat production of animals on feed, computed by Krogh's (7) and Andersen's (1) methods*

Experiment, animal, period, and subperiod No.	Total CO_2 produced, intermittent sample	Total O_2 consumed, intermittent sample	Respiratory quotients			Total heat production				
				Nonprotein		Computed		Observed	Computed / Observed	
			Total	According to Krogh	According to Andersen	According to Krogh	According to Andersen		According to Krogh	According to Andersen
Experiment 221F:	*Liters*	*Liters*				*Calories*	*Calories*	*Calories*	*Per cent*	*Per cent*
Cow 874—										
Period 1 (3 (night)	1,233.7	1,090.4	1.131	0.896	1.093	5,473.0	5,455.5			
Period 1 (4 (day)	1,246.5	1,107.7	1.125	.897	1.089	5,556.0	5,539.6			
Per day						11,029.0	10,995.1	11,076.9	99.6	99.3
Period 2 (3 (night)	893.5	855.2	1.045	.794	.998	4,213.5	4,230.8			
Period 2 (4 (day)	895.2	878.3	1.019	.774	.974	4,305.6	4,322.2			
Per day						8,519.1	8,553.0	9,125.8	93.4	93.7
Cow 887—										
Period 1 (3 (night)	1,078.5	987.8	1.092	.827	1.041	4,912.4	4,917.0			
Period 1 (4 (day)	1,169.8	1,071.6	1.092	.840	1.040	5,340.6	5,344.2			
Per day						10,253.0	10,261.2	10,151.1	101.0	101.1
Period 2 (3 (night)	870.3	768.1	1.133	.912	1.101	3,858.4	3,843.5			
Period 2 (4 (day)	866.8	897.8	.965	.736	.925	4,350.1	4,365.3			
Per day						8,208.5	8,208.8	8,348.8	98.3	98.3
Cow 886—										
Period 1 (3 (night)	1,330.2	1,292.5	1.029	.773	.976	6,355.8	6,379.7			
Period 1 (4 (day)	1,340.3	1,275.6	1.051	.784	.994	6,298.8	6,326.0			
Per day						12,654.6	12,705.7	13,559.2	93.3	93.7
Period 2 (3 (night)	1,359.6	1,184.7	1.148	.864	1.082	5,968.3	5,954.0			
Period 2 (4 (day)	1,399.3	1,233.7	1.134	.863	1.072	6,204.9	6,194.6			
Per day						12,173.2	12,148.6	12,483.4	97.5	97.3
Experiment 235:										
Steer 250—										
Period 2 (1 (day)	876.5	908.8	.964	.787	.919	4,459.8	4,471.8	4,342.5	102.7	103.0
Period 2 (3 (day)	891.0	906.3	.983	.801	.935	4,466.0	4,479.3	4,346.1	102.8	103.1
Period 2 (5 (day)	866.1	853.0	1.015	.823	.962	4,231.7	4,243.9	4,299.4	98.4	98.7
Period 3 (1 (day)	1,195.9	1,121.6	1.066	.846	1.001	5,620.0	5,640.0	5,771.7	97.4	97.7
Period 3 (3 (day)	1,166.9	1,117.2	1.044	.820	.980	5,567.5	5,587.5	5,645.5	98.6	99.0
Period 3 (5 (day)	1,217.2	1,163.5	1.046	.832	.984	5,806.4	5,826.3	5,711.0	101.7	102.0
Steer 260—										
Period 2 (1 (day)	838.7	787.3	1.065	.886	1.015	3,952.1	3,958.4	4,069.6	97.1	97.3
Period 2 (3 (day)	836.3	840.4	.995	.814	.948	4,150.6	4,162.2	4,054.8	102.4	102.6
Period 2 (5 (day)	843.2	831.3	1.014	.830	.965	4,123.5	4,135.3	4,166.8	99.0	99.2
Period 3 (1 (day)	1,136.1	1,064.4	1.067	.862	1.009	5,334.5	5,348.1	5,380.9	99.1	99.4
Period 3 (3 (day)	1,148.4	1,080.9	1.062	.859	1.005	5,413.6	5,427.7	5,236.6	103.4	103.6
Period 3 (5 (day)	1,116.3	1,071.9	1.041	.824	.981	5,333.7	5,352.6	5,245.4	101.7	102.0

The essential difference between the quotients computed by the two methods is that the Andersen quotient covers the metabolism of the animal and the oxidation of the methane, while the Krogh quotient covers only the metabolism of the animal, and neither the oxidation of the methane nor the CO_2 of fermentation. The different

use of the two quotients in the computation of the heat production is in harmony with this difference in significance, and yields results which are virtually identical. There is no point, therefore, in comparing these essentially different respiratory quotients.

TABLE 9.—*Heat production of animals on feed, computed by Anderson's (1) method, using CO_2 in continuous sample*

Experiment, animal, period, and subperiod Nos.	Total CO_2 produced	Non-protein respiratory quotient	Total heat production	
			Computed	Computed / Observed
Experiment 221F:				
Cow 874—	*Liters*		*Calories*	*Per cent*
Period 1 (3 (night)	1,236.7	1.093	5,470.1	
Period 1 (4 (day)	1,252.3	1.089	5,564.8	
Per day			11,034.9	99.6
Period 2 (3 (night)	967.2	.998	4,604.6	
Period 2 (4 (day)	977.2	.974	4,743.5	
Per day			9,348.1	102.4
Cow 887—				
Period 1 (3 (night)	1,090.4	1.041	4,974.5	
Period 1 (4 (day)	1,177.4	1.040	5,382.6	
Per day			10,357.1	102.0
Period 2 (3 (night)	884.6	1.101	3,908.1	
Period 2 (4 (day)	883.4	.925	4,456.0	
Per day			8,364.1	100.2
Cow 886—				
Period 1 (3 (night)	1,458.6	.976	7,040.9	
Period 1 (4 (day)	1,478.0	.994	7,023.0	
Per day			14,063.9	103.7
Period 2 (3 (night)	1,395.3	1.082	6,120.6	
Period 2 (4 (day)	1,420.5	1.072	6,292.5	
Per day			12,413.1	99.4
Experiment 235:				
Steer 259—				
Period 2 (1 (day)	885.0	.919	4,516.3	104.0
Period 2 (3 (day)	898.8	.935	4,519.5	104.0
Period 2 (5 (day)	863.0	.962	4,229.4	98.4
Period 3 (1 (day)	1,245.9	1.001	5,888.8	102.0
Period 3 (3 (day)	1,231.9	.980	5,917.9	104.8
Period 3 (5 (day)	1,225.7	.984	5,867.5	102.7
Steer 260—				
Period 2 (1 (day)	844.6	1.015	3,986.2	98.0
Period 2 (3 (day)	844.0	.948	4,201.6	103.6
Period 2 (5 (day)	855.7	.965	4,199.4	100.8
Period 3 (1 (day)	1,176.5	1.009	5,550.0	103.1
Period 3 (3 (day)	1,153.0	1.005	5,447.9	104.0
Period 3 (5 (day)	1,139.8	.981	5,473.7	104.4

The heat production during fast was computed in two ways, as shown in Table 7—using the gravimetrically determined CO_2 from a continuous air sample and the volumetrically determined CO_2 from the intermittent half-hour samples, the intermittent O_2 being used, as determined, with the intermittent CO_2, but being corrected for use with the continuously determined CO_2 so as to give the same respiratory quotient as obtained from the intermittent CO_2 and O_2. In 6 out of 14 twelve-hour subperiods the intermittent CO_2 and O_2 gave the higher heat production; and the heat production as computed by either method was higher than the directly observed heat produc-

tion in 5 cases out of 11. Also, it is apparent that the mean deviation of the results based on the intermittent samples would be much less than that of results based on the continuous CO_2, with oxygen computed to give the same respiratory quotient as that derived from the intermittent CO_2 and O_2. This method of computation from the continuous CO_2 determination and an oxygen value computed to harmonize with the respiratory quotient determined from the intermittent air samples, seems to be of doubtful validity.

Table 8 compares the values for heat production as obtained by Krogh's (7) and Andersen's (1) methods. The practical identity of the results obtained by the two methods shows that even though they are based upon somewhat different considerations, and appear to be distinctly different, they are essentially the same; in other words, the factors used by Krogh for computing the CO_2 of fermentation and the heat of fermentation are such that the heat production computed by the two methods agrees almost exactly.

Table 9 exhibits the heat production of animals receiving feed, computed by the method of Andersen, from the continuous CO_2 determination, and the computed O_2 to correspond.

The correspondence between the computed and the directly observed heat production is good, but leaves improvement still to be desired, and such improvement seems perfectly practicable in the light of the obviously remediable imperfections of the technic followed in the respiratory quotient procedure. Among 18 comparisons all of the computed values were between 98 and 104.8 per cent of the directly observed values.

The desired improvements in the technic employed in the respiratory-quotient method are as follows: (1) A continuous and accurately representative sample of the outcoming air from the respiration chamber, for the determination of oxygen; (2) the number of oxygen estimations made with a given pyrogallate solution should be definitely regulated; (3) the method of accounting for the urinary outgo during fast should be improved either by catheterizing, if the subject is a female, or by observing the interval of time represented, and the weight of the separate portions as passed, if the subject is a male.

SUMMARY

The computation of the heat production of cattle by the respiratory-quotient method, as modified by either Andersen or Krogh on account of the extensive fermentation of carbohydrates in the ruminant alimentary tract, gives results which agree very well with direct heat measurements.

In spite of the fact that the procedure followed in the indirect method was imperfect in a number of details, in 18 comparisons with the direct method all of the computed values were between 98 and 104.8 per cent of the directly observed values.

Andersen's and Krogh's methods of computation of the heat production of cattle, while somewhat different in theory and while yielding respiratory quotients differing in magnitude and in significance, yield virtually indentical values for heat production.

Eighteen determinations of the computed heat production according to Andersen, divided by the directly observed heat production, differed from a similar value involving Krogh's method by 0.1 to 0.4 per cent, the average being 0.24 per cent.

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In view of the variability in the composition of the outcoming air from the respiration chamber, as determined in samples taken at half-hour intervals, and as affected especially (1) by the position of the animal as to standing or lying, (2) by the activity of the animal, (3) by the time elapsed since change of position, and (4) by the time elapsed since feeding, no short-time period of observation can be assumed accurately to represent the whole day. The products of the extensive fermentation of carbohydrates constitute an important factor in this variation.

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SABAL CAUSIARUM (COOK) BECCARI: A NEW HOST OF THE COCONUT BUD-ROT FUNGUS[1]

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THE HOST

Sabal causiarum (Cook) Beccari is endemic in Porto Rico, where it is commonly known as the "hat" palm. It is most abundant in the southwestern section, where the leaves are used in the manufacture of hats, baskets, and other articles. The youngest leaf is cut as soon as it emerges from the inclosing sheath. At this stage the pinnae have not expanded and are of a cream color. They are bleached, split into narrow strips, and used for weaving, which is done entirely by hand. The young leaves are sold by the growers at 75 cents to $1.25 per dozen, and the palms are considered more valuable than coconut palms. Little effort has been made to grow the palm under grove conditions, and it is found largely in thickets or scattered through coconut groves. The palm is a very slow grower, and its slowness may be accentuated by the removal of its emerging leaves from the bud.

THE DISEASE

Early in 1926 the attention of the writer was called to a disease attacking hat palms growing a few miles south of Mayaguez. The disease was found to be a bud rot showing symptoms identical with those of coconut bud rot. The earliest indication of infection was the death of the young emerging leaf, followed by the death of a few of the youngest expanded leaves. This dead group eventually fell away, leaving the palm conspicuous by the absence of young leaves (figs. 1 and 2). The older leaves were not attacked, but died gradually, remaining attached to the trunk instead of falling away as do the leaves of bud-rot-infected coconut palms. The difference in symptoms is deemed of no significance and is due to the normal persistence of the petioles in Sabal.

The growing point of infected palms was reduced to a watery mass, emitting an odor which was indistinguishable from that associated with rotted coconut tissue. The bases of the young petioles were rotted off and the growing point with its leaf bases could easily be pulled from the inclosing sheath, leaving a cylindrical cavity about 6 inches in diameter and 18 inches in depth. Some of the older leaf sheaths bore brown decaying spots, similar to those in bud rot of coconut, previously recorded by Ashby (*1*),[2] Sundararaman (*13*), and the writer (*15*).

In 1923 a survey of the western coast of the island for coconut bud rot showed no cases of bud rot among either coconuts or hat palms south of Mayaguez. In 1926 a survey, conducted in cooperation with the Porto Rico Department of Agriculture and Labor, revealed 320 dying or recently dead coconut palms. The dying palms were infected by *Phytophthora palmivora* Butler. The survey was extended

[1] Received for publication Dec. 11, 1926; issued June, 1927.

[2] Reference is made by number (italic) to "Literature cited," p. 887.

to include hat palms, and disclosed 23 dying and 189 recently dead specimens.

In view of the facts (1) that the disease had become epiphytotic among both coconut and hat palms at about the same time; (2) that the hosts are closely related; and (3) that the symptoms of the disease

FIG. 1.—A healthy hat palm (*Sabal causiarum*). Note the erect young leaf in the center of the crown and compare with Figure 2. The leaf blade was removed from the cut petioles for weaving

were identical on both palms, the coidentity of the causal organism was regarded as highly probable. This opinion was further strengthened by the close and constant association of cases of bud rot of the two hosts. In most cases a diseased coconut palm was found growing within 75 feet of diseased hat palms, and in some instances the asso-

ciation was more intimate (fig. 3). No bud rot was found among either coconuts or Sabals growing about 2 miles north of the infected area.

THE ORGANISM

Microscopic examination of brown spots on leaf sheaths inclosed within the crown showed the presence of densely granular, nonseptate

FIG. 2.—*Sabal causiarum* attacked by bud rot. Note the absence of erect young leaves in the center of the crown

mycelium and chlamydospores (fig. 4). Isolations from such tissues resulted in pure cultures of a Phytophthora. Isolations from soft, decayed, growing-point tissues produced bacteria only. The same result had previously been obtained with coconut bud rot (*15*).

In pure cultures the Sabal strain behaves very similarly to the coconut strain. The two strains were grown in parallel cultures at room

temperature for comparison. The coconut strain referred to throughout this discussion is a subculture of the strain used by the writer (*15*) in 1924 to establish the causal organism of coconut bud rot in Porto Rico. Although the strain had been grown on culture media during two years, its reactions to the various media showed no perceptible differences from those observed when the strain was newly isolated.

FIG. 3.—Left, hat palm attacked by bud rot; right, coconut palm attacked by bud rot

On potato-dextrose agar plates both strains produced thin, appressed, spreading, regular mycelia, which are radiate and homogeneous from below. This radiate type of growth is to be distinguished from the flocculent or lumpy, uneven type which is characteristically displayed by some Phytophthora strains. This radiate type is well described by Leonian's (*10*) term "smooth combed." After 72 hours the average diameter of the coconut strain was 29 mm.,

whereas that of the Sabal strain was 37 mm. In potato-dextrose agar both strains at two weeks showed profuse aerial mycelium, abundant chlamydospores, and fairly abundant conidia (sporangia). There was some germination by zoospores in the Sabal strain, but zoospores were not observed in the coconut strain.

On potato-agar plates the growth of both strains was thin, appressed, spreading, regular, and radiate to slightly granular.

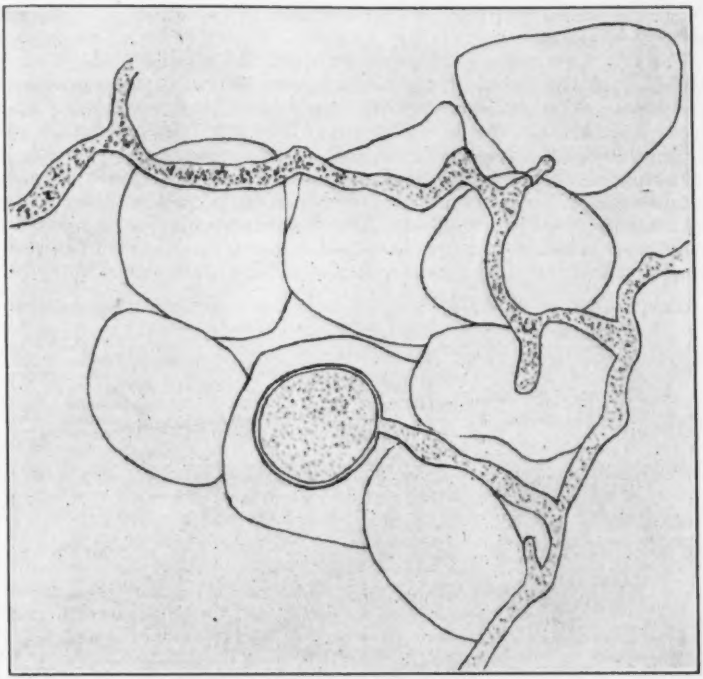

FIG. 4.—Hyphae and chlamydospore in a petiole of *Sabal causiarum* attacked by bud rot. × 644

After 72 hours the average diameter of the coconut strain was 47 mm.; that of the Sabal strain 38 mm.

On beef-dextrose agar plates both strains produced a meager, thin, appressed, slightly irregular, radiate growth. After 72 hours the coconut strain averaged 12 mm. in diameter, and the Sabal strain 11 mm.

On oatmeal-agar plates the colonies of both strains were very thin, appressed, spreading, regular, radiate. After 72 hours the coconut strain averaged 68 mm. in diameter, and the Sabal strain 61 mm. In oatmeal-agar tubes at two weeks both strains produced a medium quantity of aerial mycelium.

On bean-agar plates both strains produced thin, appressed, spreading, regular, radiate to flocculent mycelia. After 72 hours the coconut strain averaged 34 mm. in diameter, and the Sabal strain 29 mm. In tubes of bean agar at four months both strains

showed moderately profuse aerial growth, with abundant conidia and very few chlamydospores.

On steamed corn meal in flasks at two weeks both strains produced a frosty growth, with very little aerial mycelium and abundant conidia and chlamydospores. Some conidia were germinated by zoospore formation in the Sabal strain, but not in the coconut strain.

On steamed green bean pods the strains made very little aerial growth, but conidia and chlamydospores were abundant. Again the Sabal strain exhibited some zoospore germination, whereas the coconut strain did not.

The only perceptible difference between the strains was the slight tendency in the Sabal strain toward germination of the conidia by zoospores. The coconut strain rarely produces zoospores. This characteristic is not due to the length of time that it has been cultured, for similar results were recorded (*15*) when it was newly isolated.

For morphological comparison, 400 conidia from 13-day-old cornmeal cultures and 400 chlamydospores from 8 to 10 day old potato-dextrose agar cultures were measured. The measurements for the coconut strain were taken from a previous publication (*15*). Table 1 shows the great similarity existing between the two strains in the size of the spores.

TABLE 1.—*Dimensions of conidia and chlamydospores of Phytophthora palmivorao from coconut and Sabal causiarum bud rot*

Class (in microns)	Number of conidia in—				Number of chlamydospores in—	
	Coconut strain according to—		Sabal strain according to—		Coconut strain according to—	Sabal strain according to—
	Length	Diameter	Length	Diameter	Length	Diameter
15.5 to 17.49	0	0	0	1	0	1
17.5 to 19.49	0	2	0	3	0	1
19.5 to 21.49	0	2	0	8	0	10
21.5 to 23.49	0	3	0	17	9	11
23.5 to 25.49	0	2	0	15	18	13
25.5 to 27.49	2	18	3	27	30	18
27.5 to 29.49	1	56	5	111	56	32
29.5 to 31.49	2	94	6	92	54	32
31.5 to 33.49	2	138	6	82	81	73
33.5 to 35.49	2	56	5	20	42	56
35.5 to 37.49	1	18	7	14	41	43
37.5 to 39.49	1	11	3	10	29	52
39.5 to 41.49	4	0	8	0	17	28
41.5 to 43.49	9	0	11	0	13	19
43.5 to 45.49	18	0	9	0	6	5
45.5 to 47.49	22	0	21	0	2	4
47.5 to 49.49	44		20	0	2	2
49.5 to 51.49	36		32		0	
51.5 to 53.49	63		44		0	
53.5 to 55.49	32		27		0	
55.5 to 57.49	29		26			
57.5 to 59.49	30		29			
59.5 to 61.49	20		23			
61.5 to 63.49	16		29			
63.5 to 65.49	15		20			
65.5 to 67.49	10		20			
67.5 to 69.49	13		18			
69.5 to 71.49	5		11			
71.5 to 73.49	7		7			
73.5 to 75.49	4		3			
75.5 to 77.49	3		3			
77.5 to 79.49	6		2			
79.5 to 81.49	0		1			
81.5 to 83.49	0		1			
83.5 to 85.49	1					
85.5 to 87.49	0					
87.5 to 89.49	2					
89.5 to 91.49	0					
Total	400	400	400	400	400	400
Average	54.94	31.68	55.39	29.83	32.96	33.85

Four hundred conidia from a diseased Sabal petiole averaged 48.76 microns in length and 35.09 microns in diameter. They were somewhat shorter and thicker than those taken from corn meal. Four hundred chlamydospores from the same petiole averaged 32.60 microns in diameter.

Trial inoculations of various hosts with the two strains revealed further similarity. Wounded inoculated eggplant fruits showed slight infections after 48 hours with both strains. Neither strain caused any pathological symptoms in wounded eggplant seedlings 30 days after inoculation. The strains proved to be nonpathogenic to cacao fruits, and to cacao, *Erythrina poeppigiana*, breadfruit, and roselle seedlings. Both strains infected wounded papaya (*Carica papaya*) seedlings. The coconut strain caused the deaths of two of five inoculated seedlings in 7 days. After 60 days two of the remaining seedlings had dark lesions arising from the point of inoculation on the stem. The Sabal strain caused the deaths of three of five inoculated plants, one at 4 days and two at 6 days. The other two seedlings remained healthy. Another paper will show that few Phytophthora strains are pathogenic to papaya seedlings.

INOCULATIONS OF COCONUT PALMS

The foregoing comparisons of the coconut and Sabal strains of *Phytophthora palmivora* establish their identity as a single species; however, it is a well-known fact that physiologic races exist among the Phytophthora and cross-inoculation is the only completely reliable means of demonstrating the responsibility of any strain for disease in more than one host.

In April, 1926, twenty 15 to 25 year old coconut palms, growing in the station grounds remote from cases of bud rot, were inoculated by pouring a water suspension of the fungi among the emerging leaves. The palms were not wounded. Ten palms were inoculated with the Sabal strain and 10 with the coconut strain. The cultures for inoculation have been prepared by growing the fungi on steamed corn meal in liter flasks, and after 20 days adding sterile water to the flasks. On the twenty-first day each palm was inoculated with about 500 c. c. of the suspensions. Ten additional palms received a sterile suspension of corn meal and water.

On August 11, 115 days after inoculation, all palms were examined for evidences of infection. Of the 10 palms which had been inoculated with the coconut strain one proved to be a typical bud-rot case, the youngest leaf having died and the growing point having completely decayed. Eight palms showed spotting of the emerging leaves typical of this method of inoculation (*15*), and one palm showed no evidence of infection.

Of the 10 palms which had been inoculated with the Sabal strain, 3 developed into typical bud-rot cases. The young dead leaves were easily pulled from the crown and their bases and growing points were reduced to a watery, malodorous mass, which in every respect was identical with that produced by the coconut strain. The 7 remaining palms showed more or less severe spotting of the leaves. On the whole, the spotting caused by the Sabal strain was more severe than that caused by the coconut strain.

The 10 control palms showed no bud rot or leaf spotting.

The results of the inoculations are believed to furnish strong evidence in favor of the transmissibility of Sabal bud rot to coconuts, and to indicate the necessity for including *Sabal causiarum* with other host plants when a campaign is undertaken for the eradication of bud rot.

The coconut strain, which had been used in 1924 when four of eight inoculated palms developed bud rot in 108 days, showed an apparent slight loss of virulence. The season of 1926 has been fully as favorable for infection as was the summer of 1924 (*15*). Leonian (*10*) has shown that mutations occur in Phytophthora, and LaRue (*9*) has suggested that fungi may decrease in virulence in culture media, due to mutations giving rise to saprophytic strains while the parasitic strains perish. To determine whether the bud-rot Phytophthora really undergoes loss of virulence on culture media, inoculations are desirable with strains which have been isolated for a longer period than were the strains reported upon.

BUD ROTS OF OTHER PALMS

A careful search through the available literature for references to the occurrence of a bud rot on *Sabal causiarum* disclosed occasional notices of bud rots of other palms. The knowledge obtained is summarized here.

Butler (*3*) in 1907 described the occurrence in India of bud rots of the palmyra palm (*Borassus flabellifer* L.) and the betel nut or areca palm (*Areca catechu* L.). He later (*4*) determined that the bud rots of the palmyra and coconut palms were caused by the same organism, *Pythium* (*Phytophthora*) *palmivora* Butl.

Coleman (*5*) in 1910 found that occasionally the bud of the areca palm was affected by rot and that the nuts were the more important infection points. The fungus (*Phytophthora arecae* (Colem.) Pethyb.) is distinct from *P. palmivora* and is apparently nonpathogenic to the coconut bud.

Johnston (*8*) noted a disease of the crown of royal palms (*Roystonea regia* (H. B. K.) Cook) in Cuba in 1912. He stated, "In the royal palm the central leaves remained healthy longest, while the surrounding leaves gradually turned brown and fell off." He did not consider the disease a true bud rot.

In 1925 (*14*) a bud rot of royal palms was reported in Mauritius. It was thought to be of bacterial origin.

Van Hall (*6*) in 1921 recorded the presence in Java of a disease of the oil palm (*Elaeis guineensis* Jacq.) resembling bud rot. The cause was unknown. In 1922 (*7*) the oil palms in Sumatra were reported to be suffering from a crown disease which was thought to be due to physiological disturbances of unknown origin.

Sharples (*11*) in Malaya in 1922 investigated a kind of bud rot of young oil palms in which the disease began with the collapse of the third or fourth leaf from the center, followed by collapse of the outer leaves. The central leaves remained healthy. He suggested that the disease was an incipient form of bud rot and that the affected area was carried away from the healthy portion by the rapid growth of the central leaves. No organism was mentioned as a possible cause of the disease, and it was not observed to be fatal. In 1925 (*12*) he adopted the term "crown disease" for the trouble.

In 1924 Burger (*2*) recorded the presence in Florida of a disease similar to bud rot on *Cocos plumosa* Hook. He wrote: "The first symptom generally noted was the falling from the crown of the newest leaf before the blade unfolded. It gave off a putrid odor. The trees from which the buds have fallen linger for a season or two before dying, but eventually all diseased trees die." This description leaves little doubt that *Cocos plumosa* is susceptible to true bud rot, and the presence of *Phytophthora palmivora* on coconuts in Florida makes it very probable that *C. plumosa* is a host of *P. palmivora*.

SUMMARY

A bud rot of *Sabal causiarum* showing symptoms identical with those of coconut bud rot is recorded and described.

Bud rot appeared on both hosts at about the same time. Diseased palms of both genera were intimately associated.

A Phytophthora was isolated from Sabal and found to be indistinguishable morphologically and in culture reactions from a coconut-infecting strain of *P. palmivora*.

Both strains proved to be slightly pathogenic to wounded eggplant fruits, distinctly pathogenic to wounded papaya seedlings, and non-pathogenic to cacao fruits and cacao, roselle, *Erythrina poeppigiana*, breadfruit, and eggplant seedlings.

Ten unwounded coconut palms were inoculated with each strain. After 115 days inoculation with the coconut strain resulted in 1 typical bud-rot case, 8 cases with infected, spotted leaves, and 1 negative case; and inoculation with the Sabal strain resulted in 3 typical bud-rot cases, and 7 cases with infected leaves. Ten control palms showed no symptoms of infection.

The results establish *Sabal causiarum* as a host of *Phytophthora palmivora* and indicate the necessity for including it in eradication work for the control of coconut bud rot.

There is evidence of slight decreased virulence in the coconut strain after it has grown on culture media for two years.

Three hosts of the coconut bud-rot fungus—*Cocos nucifera*, *Borassus flabellifer*, and *Sabal causiarum*—have been definitely established. *C. plumosa* probably should be added to the list, although it has not been used as a host in cross-inoculation work.

Bud or crown diseases slightly resembling bud rot have been reported on *Roystonia regia* in Cuba and Mauritius and on *Elaeis guineensis* in Java, Sumatra, and Malaya, but evidence fails to show that either of these palms is susceptible to invasion by *Phytophthora palmivora*.

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THE DISCOLORATION OF CANNED CRANBERRIES[1]

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INTRODUCTION

Cranberry sauce preserved in tin cans sometimes becomes much discolored so that when the cans are opened the natural red color is found to have changed to a dirty brown, or black, which makes the sauce unappetizing in appearance. The causes of this discoloration have been under investigation at this experiment station.

A possible chemical cause of the change in color is the action of soluble aluminum, iron, or tin on the coloring matter of the cranberries, since compounds of these metals have long been used by dyers to modify their colors. In canning cranberries, the fruit is cooked in aluminum kettles and preserved in tin cans which are made of thin sheet iron coated with tin. The cans employed in the commercial preserving of cranberries are enameled; that is, the sheets of tin are coated with lacquer before cutting and bending them into cans.

PRELIMINARY EXPERIMENTS

Preliminary experiments with some cranberry sauce that had been prepared in glass were made by spreading the sauce in a glass dish and adding to the surface of the sauce a variety of soluble compounds of aluminum and of iron.

Aluminum compounds produced no perceptible color changes. Ferric chloride, ferric ammonium sulphate, and ferric ammonium citrate, when added to the sauce either in crystals or in drops, quickly darkened the red sauce in a widening area about the spots of application.

The best sauce obtained from tin cans showed a faint brown streak down the side where it was in contact with the seam of the can and also around the top. It was easy to observe the appearance of the sauce because it could usually be removed from the can as a cylinder of firm jelly. The most reasonable explanation of this discoloration appeared to be that in bending and cutting the sheet of tin, the lacquer and the tin coatings were slightly broken, thus exposing sufficient iron to the sauce to change its color.

Tannin had been noted as present in the cranberry in another investigation. The skins of the berries had been extracted with ordinary ether, which contained a little alcohol and water. The extract consisted of wax and resin, but darkened upon application of iron salts. When this reaction occurred, the extract was washed with hot water. The washings turned green on the addition of ferric

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chloride and ferric acetate but did not indicate sufficient tannin present to produce the discoloration observed in the canned fruit.

It was considered advisable to isolate the pigment of the cranberry and to study its behavior toward the soluble compounds of aluminum, tin, and iron. Willstaetter and his students have studied the pigments occurring in many of the flowers and fruits, and their published papers have been compiled by Perkin and Everest.[2] Among the pigments described was the one occurring in the European cranberry, *Vaccinium vitis idaea*.[3] Willstaetter's method was followed in most of its details in extracting and purifying the pigment contained in our American cranberry, *Vaccinium macrocarpum*.

The coloring matter of the cranberry is confined almost wholly to the skin of the fruit, but when the skin is crushed or cooked some of the pigment diffuses throughout the pulp, coloring the mass.

EXPERIMENTAL PROCEDURE

Following Willstaetter's procedure, the cranberries were crushed and pressed to remove as much juice and pulp as possible. The moist residue, consisting mainly of skins, was placed in large glass flasks, and enough glacial acetic acid was added to cover the mass. The flasks were allowed to stand about one week, and their contents then filtered through glass wool. Owing to the presence of gelatinous matter it was almost impossible to filter the extract through paper or linen.

The residues were extracted a second and third time in a similar manner. The amount of pigment in the third extraction was slight, although the skins remained red in color. A further extraction with alcohol also failed to remove more than enough to color the solution.

The acid extract, which was brilliant red in color, was poured into two and one-half times its volume of ether, shaken repeatedly, and allowed to stand 24 to 48 hours. The pigment settled as a heavy, oily liquid from the first extraction but as a sticky, waxy mass from the third. The acid-ether liquid was slightly colored and was decanted carefully from the pigment. The ether and acetic acid were recovered by distillation and used for further extractions.

The pigment was purified after the method followed with the European cranberry, picric acid being employed first and finally hydrochloric acid to form crystalline compounds. The final crystals obtained with alcoholic hydrochloric acid were scalelike, lustrous, dark red, and almost black in some lights.

The crystals were readily soluble in methyl and ethyl alcohols but, unlike the pigment described by Willstaetter, they were only slightly soluble in water. It was also noticed that no successive crop of crystals from alcoholic solutions would redissolve completely in a fresh lot of alcohol, but would leave a slight precipitate, black in color and insoluble in methyl or ethyl alcohol, water, and acetic or hydrochloric acids. After the insoluble residue had been moistened with concentrated hydrochloric acid and ethyl alcohol had been added, a slight solubility colored the alcohol.

[2] PERKIN, A. G., and EVEREST, A. E. THE NATURAL ORGANIC COLOURING MATTERS. 655 p. London, New York [etc.], 1918.
[3] PERKIN, A. G., and EVEREST, A. E. Op. cit. p. 286.

Willstaetter obtained 1.6 gms. idaein chloride from 10.7 kgm. of cranberry skins, which would be equivalent to 40 kgm. of berries, calculated from other data given by him.

The writer used one-half barrel of Early Black cranberries, a highly colored American variety. Rejecting unsound fruit, approximately 22 kgm. of berries were used. The resultant masses of crystalline chloride of the pigment, when collected together, amounted to 2.1 gm. A half barrel of MacFarlin cranberries yielded much less in volume of crystals, but no weight records were taken. Early Black cranberries produce a much darker cooked product than other common varieties, due undoubtedly to the larger content of coloring matter in the berries.

A solution of 13 mg. of the hydrochloride dissolved in 15 c. c. of water and 3 drops of concentrated HCl, was prepared and used in the following tests. To 3 c. c. of color solution was added 3 c. c. of standard iron solution containing 0.3 mg. Fe. After several hours the color had become pale and a fine, granular, dark precipitate was noted. Minute crystals of ferric ammonium sulphate were added to 2 c. c. of the color solution, which was quickly decolorized with the formation of a fine, granular, dark precipitate. To a third portion of the color solution a small scale of ferric ammonium citrate was added, which slowly decolorized the solution with the formation of the dark precipitate. Aluminum salts showed no noticeable effects.

A methyl alcohol solution of the hydrochloride crystals was prepared, sufficient pigment being used to give a brilliant, clear, red color. Portions of about 3 c. c. each were used for tests with the different salts. Aluminum nitrate and ammonium aluminum sulphate caused little, if any, change in the solution. Stannous chloride produced a purplish tint. The iron salts darkened the solution and formed dark precipitates.

The contents of one can of cranberry sauce was much darkened, black particles were observed in the syrup, and the red color was nearly faded out. Several scratches which showed in the lacquer in the interior of the can appeared to be corroded. A weighed quantity of the darkened sauce (50 gm.) was dried and ashed. For comparison an equal amount of Early Black variety cranberry sauce, cooked and preserved in glass, was also ashed. The comparison of these two lots was made colorimetrically. By ordinary analytical methods cranberries normally contain no more than a trace of iron. The discolored product from the corroded can contained between six and seven times as much iron as the sauce from glass.

Some fresh acetic acid extract of the cranberry pigment was prepared from freshly crushed fruit. The pigment was precipitated by ether and redissolved in a little acetic acid. This acid solution was diluted with water to a clear, transparent, red tint and divided into two portions. To one portion a small coil of iron piano wire was added and to the other a small fragment of aluminum foil. The vessels containing these two portions, covered from dust, were allowed to stand for observation.

The solution with the aluminum foil was unaffected throughout the observation, which continued for two weeks.

The solution containing the iron wire began in the course of hours to produce a precipitate which steadily increased in amount, while the tint became progressively paler.

At the end of 72 hours the precipitate was collected by filtering through two filters of ash-free paper 4½ cm. in diameter. The filters were repeatedly washed with hot water and were finally separated and dried. The inner filter contained all the precipitate. Each paper was incinerated in a clean porcelain crucible. The paper with the precipitate yielded an ash stained with iron, which on solution gave a bright color reaction for that metal. The other filter gave but a trace of ash and a very faint color reaction for iron. The evidence was positive that the precipitate contained iron and that the filter did not adsorb the iron from the solution.

SUMMARY

The discoloration of canned cranberry sauce is due to the formation of soluble iron from the inner surface of the can and to the reaction of the iron with the coloring matter and, to a less extent, with the tannin in the fruit.